HISTORICAL OBSERVATIONS OF WILDLIFE IN KENYA:

A WEB GIS APPLICATION

by

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A Thesis Presented to the
FACULTY OF THE USC DORNSIFE COLLEGE OF LETTERS, ARTS AND SCIENCES
UNIVERSITY OF SOUTHERN CALIFORNIA
In Partial Fulfillment of the
Requirements for the Degree
MASTER OF SCIENCE
(GEOGRAPHIC INFORMATION SCIENCE AND TECHNOLOGY)

May 2025

To Mom and Dad

Acknowledgements

I would like to thank Dr. Ruddell, Dr. Loyola, Dr. Swift, and Dr. Osborne for their precious guidance, support and encouragement throughout this project. Their expertise and feedback have been instrumental in shaping the direction and quality of my work. I appreciate all my incredible colleagues and classmates, who have consistently supported me on and shown understanding throughout this challenging yet rewarding journey. Finally, I am very grateful to my friends and family, who have been my constant source of comfort and inspiration. Your support means the world to me.

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List of Abbreviations

API	Application Programming Interface
CSV	Comma-Separated Values
CSS	Cascading Style Sheets
GBIF	Global Biodiversity Information Facility
GIS	Geographic Information System
GPS	Global Positioning System
HTML	Hyper Text Markup Language
JSON	JavaScript Object Notation
NDVI	Normalized Difference Vegetation Index
RS	Remote Sensing
SWOT	Strengths, Weaknesses, Opportunities, Threats
UAV	Unmanned Aerial Vehicle
VGI	Volunteered Geographic Information
WGS 84	World Geodetic System 1984

Abstract

The conservation of wildlife is a global imperative, driven by the need to preserve biodiversity and maintain the delicate balance of ecosystems. In Africa, a continent renowned for its rich and diverse wildlife, these efforts are particularly critical. However, the challenges posed by habitat loss, climate change, and illegal poaching have intensified, necessitating innovative approaches to wildlife conservation. In response to these challenges, this thesis presents the development and implementation of the Historical Kenya Wildlife Observation App, a Geographic Information System (GIS)-based platform designed to document historical and report new observations of wildlife across Kenya.

The Historical Kenya Wildlife Observation App is an advanced tool that leverages the power of GIS and community engagement to create a comprehensive database of wildlife movements and populations. Built on a foundation of user-generated data, sourced primarily from iNaturalist (iNaturalist 2024), the app provides historical insights into the distribution of species, helping conservationists, researchers, and policymakers make informed decisions. By integrating automated data processing, interactive maps, and educational resources, the app serves as both a scientific tool and a platform for public participation in conservation efforts.

Results of this thesis show the technical development of the Historical Kenya Wildlife Observation App. This platform integrated GIS and VGI to track historical wildlife observations in Kenya, cooperated with user interface design techniques and data management strategies. It

also examines the application's potential impact on wildlife conservation, highlighting the role of digital platforms in fostering community engagement and improvements may applied in the future.

Chapter 1 Introduction

This project is an innovative GIS initiative to enhance the conservation efforts for Kenya's diverse wildlife. This project utilizes historical data from iNaturalist, focusing on four taxa—amphibians, mammals, aves, and reptiles—collected between 2010 and 2020. By leveraging Volunteer Geographic Information (VGI), the project seeks to provide a comprehensive and interactive platform that enables users to explore historical wildlife observations in Kenya.

A primary objective of this project is to create a powerful, user-friendly, multi-platform web application that can be accessed and utilized by individuals with varying levels of map-related knowledge. The application is designed to serve as an informative tool that offers detailed spatial information on wildlife, including the location, time of observation, and associated images. The emphasis on historical data ensures that the platform is a repository of past wildlife records and a tool for understanding long-term trends in species distribution.

In addition to its historical focus, the project includes a feature for reporting new wildlife observations. This new observation report function allows users to contribute fresh data. These contributions will be integrated into the public-facing application every five years to reduce the risk of poaching. This approach balances the need for updated information with the imperative of wildlife protection.

The project also aims to increase public awareness and engagement in wildlife conservation. By linking to various informative websites, including those dedicated to wildlife services and anti-poaching efforts, the web map is a gateway for users to explore Kenya's wildlife and the importance of protecting it. Through this multifaceted approach, the project addresses the weaknesses and threats (as mentioned in chapter 3.1) associated with existing VGI platforms like iNaturalist. It builds on their strengths to create a more robust and secure tool for wildlife conservation in Kenya.

1.1 Motivation

The motivation behind the historical wildlife observation project stems from a confluence of factors, including the urgent need for effective wildlife conservation strategies, the increasing availability and potential of VGI, and the limitations of traditional methods of animal observation and monitoring.

From a conservation perspective, the rapid decline of biodiversity globally (Butchart, 2010), and specifically in regions like Kenya, necessitates innovative approaches to wildlife monitoring. Traditional methods, such as field surveys and camera traps, while valuable, often require significant resources, are time-consuming, and are limited in spatial and temporal scope. These methods, though accurate, can only cover a fraction of the vast and varied landscapes where wildlife exists, leading to gaps in data and potential oversight of critical changes in wildlife populations and distributions (Liu, 2024).

This project leverages the power of VGI, specifically data sourced from iNaturalist, to fill these gaps by providing a continuous stream of observations collected by a diverse range of contributors. Unlike traditional animal documentation methods, which are often restricted to professional researchers and conservationists, VGI democratizes data collection by enabling anyone with a smartphone and a passion for nature to contribute valuable information. This crowdsourcing approach not only increases the volume of data collected but also enhances the geographic and temporal coverage, offering a more comprehensive view of wildlife distribution and trends (Siriba, 2017).

Moreover, this project addresses one of the critical challenges associated with VGI—data accuracy and the potential for misuse. By focusing on historical data (2010-2020) and implementing a five-year delay on the public release of new observation data, the project mitigates the risk of poaching, which is a significant concern in regions rich in biodiversity like Kenya. This approach contrasts with traditional methods, where data might be released immediately, potentially compromising the safety of endangered species.

Beyond its contributions to conservation and data collection, this project aims to increase public awareness and engagement in wildlife protection. The user-friendly, interactive web application provides an accessible platform for individuals to explore and learn about Kenya's wildlife, encouraging a sense of responsibility and stewardship among a broader audience. Research has shown that educational engagement with wildlife fosters conservation behaviors and a deeper connection to biodiversity (Ballantyne & Packer, 2009). Unlike traditional wildlife monitoring methods, which are typically confined to experts, this project actively involves the public, fostering inclusivity and enhancing collective efforts in conservation.

Ultimately, the motivation for this project is rooted in the desire to create a more effective, inclusive, and secure method for wildlife monitoring that leverages modern technology and community participation to address the limitations of traditional animal observation methods. This project represents a step forward in the use of GIS and VGI for conservation, aiming to not only protect wildlife but also to empower people to play an active role in the preservation of Kenya's natural heritage.

In June 2024, midway through the development of this project, Esri and iNaturalist launched a beta version of a wildlife tracking map. This new tool reflects the increasing recognition of GIS and VGI as essential biodiversity monitoring and conservation technologies. While this beta version aligns with the broader goals of this thesis, it was released after the project's design and implementation began in January 2024. The existence of such advancements underscores the relevance of this research. It highlights the importance of historical data integration and visualization.

1.2 Study Area

Kenya is home to a wide range of habitats, from savannas and grasslands to forests, wetlands, and coastal regions, each supporting a unique array of species. Kenya’s wildlife includes iconic species such as elephants, lions, giraffes, and rhinoceroses, alongside a rich variety of bird species, amphibians, and reptiles (Kenya Wildlife Tours, 2025). The map in Figure 1 provides a detailed overview of Kenya’s geographical and ecological features, focusing on regions critical to wildlife conservation. The major cities in Kenya are labeled with red points. The polygons of other crucial wildlife areas including wetlands, national parks, national reserves, and nation sanctuaries are highlighted with distinct colors.

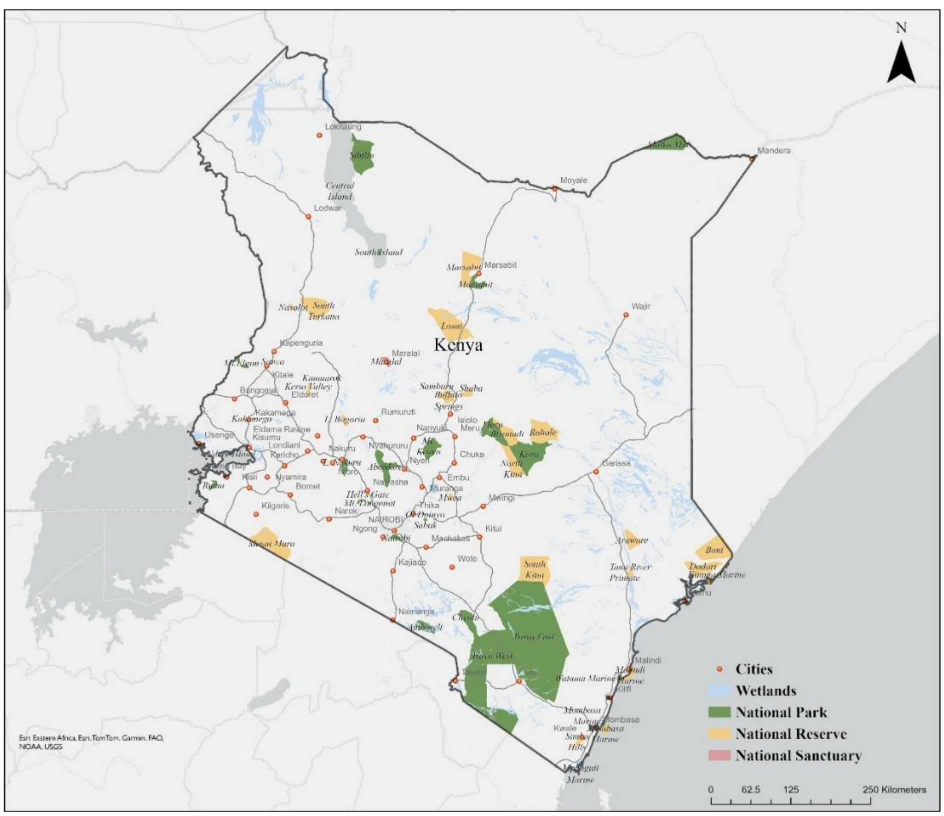


Figure 1. Study Area, the Kenya National Boundary

1.3 Methods Overview

This section outlines the key steps and techniques used to develop the Historical Observation of VGI Data Web Map for Wildlife in Kenya. The methods employed encompass several phases, including data collection, data processing and cleaning, GIS integration, web frame design, and the design and implementation of the ArcGIS Experience Builder for user interaction.

1.3.1 Data Collection and Processing

The primary data source for this project is iNaturalist, a platform aggregating VGI contributed by users globally. The project focuses explicitly on historical data from 2010 to 2020, covering four key taxa: Amphibians, Mammals, Aves, and Reptiles within Kenya. The raw data was extracted from iNaturalist, cleaned, and pre-processed to ensure accuracy and relevance. This step involved filtering the data to remove duplicates, correcting spatial inaccuracies, and categorizing the observations according to the selected taxa.

1.3.2 Data Visualization

The processed data was then integrated into a GIS platform to create a spatially accurate and interactive web map. This process involved georeferencing the observation data to align it with Kenya's existing geographic frameworks. ArcGIS Pro tools were used for data visualization, classification, and analysis. The map layers were designed to be informative and user-friendly, enabling users to interact with the data and visually explore wildlife trends.

1.3.3 Web Map Development

The core of this project is the development of an interactive web map designed to be both powerful and accessible to users with varying levels of technical expertise. The map was developed using modern web mapping technologies such as Esri ArcGIS products, which has features that allow users to view and explore wildlife data spatially. The interface includes tools for zooming, panning, and querying the data, making it easy for users to access detailed information about each observation, including location, time, and accompanying images.

1.3.4 New Observation Report

A new observation report feature was developed to enhance the functionality of the web map. This feature allows users to submit new wildlife observations directly through the web application. These reports are stored in a database and scheduled for public release every five years to protect sensitive wildlife information from potential misuse, such as poaching. The observation report system is integrated with Esri Survey123 (Esri 2025), enabling efficient data collection and management.

1.3.5 Web Appearance Design

The web page design focused on user experience, accessibility, and responsiveness. The website was designed using HTML, CSS, and JavaScript to make it visually appealing and functional across different devices and screen sizes. The design process involved creating a clean and intuitive layout that prioritizes ease of navigation while maintaining the integrity of the data presented. Effective UX/UI principles are critical for web GIS design to ensure accessibility, usability, and engagement for diverse users." (Nielsen and Norman, 2020)

1.4 Thesis Overview

The remainder of this thesis is structured into four key chapters. *Chapter 2: Related Literature* explores relevant topics including the role of VGI in wildlife conservation, its application in tracking species distribution, and challenges related to the quality and accuracy of VGI data. The chapter also discusses the strengths and limitations of using GIS for wildlife monitoring, drawing from prior research. *Chapter 3: Methods* details the methodological approach employed in the study, focusing on data collection, cleaning, GIS integration, and the design of the ArcGIS web application. It also outlines the process of developing the new wildlife observation reporting system. *Chapter 4: Results* presents the outcomes of the methodological steps, including the creation of an interactive web map and the integration of user-submitted wildlife observations. Lastly, *Chapter 5: Conclusions* reflects on the findings, discusses the implications for wildlife conservation, and suggests future research avenues to enhance the use of VGI in environmental protection efforts.

Chapter 2. Related Work

This chapter explores the foundational role of emerging technologies in wildlife conservation, emphasizing the integration of GIS, web map design, and VGI. These tools empower conservationists and the public to make informed decisions and contribute to effective wildlife management. This section reviews relevant studies to contextualize the integration of these technologies, highlighting their potential and challenges that could affect the outcome of the project.

2.1 GIS in Animal Conservation

GIS play an instrumental role in animal conservation by enabling the mapping and analysis of migration patterns. By providing spatial data and visualization, conservationists can make data-driven decisions about habitat preservation and design effective wildlife corridors. Additionally, GIS aids in monitoring human activities like poaching, contributing to more proactive conservation strategies.

2.1.1 GIS Mapping of Subtropical Estuarine Habitats

Zharikov (2005) demonstrates the application of aerial photography and GIS in the mapping and characterization of estuarine landscapes, the environments where freshwater from rivers mixes with saltwater from the sea, creating rich habitats for diverse aquatic species. The study examines the intricate relationships between estuarine landscapes and wildlife by leveraging aerial photography and GIS to analyze spatial patterns and habitat structures. The author emphasizes that estuarine environments provide critical ecosystem services and habitats for diverse wildlife species. Understanding their structure and distribution is crucial for conservation strategies. The methodology involves capturing high-resolution aerial imagery, which provides detailed insights into the landscape structure. This imagery is integrated into GIS to create detailed maps highlighting various landforms, vegetation patterns, and other significant features. Zharikov (2005) categorizes different habitat types based on their spatial characteristics, vegetation, and hydrological properties, giving conservationists a comprehensive view of the region's ecological diversity.

The results indicate that aerial photography combined with GIS enables a precise classification of landscape features, offering a robust tool for managing wildlife habitats. The study reveals significant habitat diversity in subtropical estuarine environments, underscoring the importance of tailored conservation strategies for each habitat type.

In the study of distribution of macrophyte species and habitats in South African estuaries by Adams et al. (2016) presented another application of GIS in mapping macrophyte species and habitats across South African estuaries. Their study highlighted the effectiveness of spatial tools in identifying ecological zones and characterizing the distribution of aquatic plant species. The research emphasized how GIS and remote sensing (RS) techniques could provide a baseline for conservation planning by monitoring environmental changes over time. Such approaches are highly relevant for biodiversity studies, particularly in aquatic and coastal ecosystems, where rapid habitat changes often occur due to anthropogenic and climatic pressures.

2.1.2 Integrating GIS and Remote Sensing for Wildlife Management

Integrating GIS and RS technologies into wildlife ecology and conservation management has revolutionized how biodiversity is studied, monitored, and protected. These tools offer spatial and temporal insights essential for addressing complex ecological challenges and formulating effective conservation strategies. Drawing on the foundational principles outlined by Fryxell et al.(2014) , alongside the methodologies explored by Acharyya et al.(2017) and Prasad et al. (2015), this section highlights how GIS and RS enhance biodiversity conservation efforts.

Fryxell et al. (2014), in their foundational text Wildlife Ecology, Conservation, and Management, emphasize the need for a comprehensive understanding of ecological principles to support conservation efforts. They highlight the importance of studying species distributions, migration patterns, and habitat use in the context of broader ecological processes. GIS and RS are pivotal in achieving these goals by enabling precise spatial analyses. Fryxell et al. (2014) stress the value of integrating ecological models with geospatial data to predict population dynamics and assess the impacts of environmental change on biodiversity. For instance, spatial tools can help delineate critical habitats and identify potential corridors that maintain genetic flow between fragmented populations. Furthermore, the authors underline the necessity of addressing human-wildlife conflicts, advocating for conservation strategies informed by detailed spatial data, such as land-use maps and human activity patterns.

Acharyya et al. (2017) explore the practical applications of GIS and RS in wildlife management and showcase their effectiveness in monitoring and protecting biodiversity. Their research demonstrates how satellite imagery and spatial analysis can detect deforestation, track habitat loss, and identify areas vulnerable to poaching. For example, they highlight a case study where satellite data was used to monitor illegal encroachments in a wildlife reserve, enabling timely interventions to mitigate habitat destruction. Acharyya et al. (2017) also emphasize the utility of GIS in mapping species distributions and analyzing habitat suitability, which is critical for reintroducing species into restored habitats. Their findings underscore the role of geospatial technologies in enabling proactive conservation measures by identifying priority zones for intervention and resource allocation.

Prasad et al. (2015) focus on integrating GIS and RS for biodiversity conservation, particularly in habitat monitoring and species distribution modeling. They discuss advanced remote sensing techniques, such as high-resolution satellite imagery and vegetation indices like the Normalized Difference Vegetation Index (NDVI), used to assess habitat quality and detect changes over time. Their research highlights how GIS-based spatial modeling has been applied to delineate biodiversity hotspots and evaluate the connectivity of wildlife corridors. For instance, they document a case study in which habitat fragmentation was analyzed using landscape metrics derived from RS data, providing actionable insights for corridor design. Prasad et al. (2015) also emphasizes the role of temporal analysis in capturing seasonal variations in species distribution, which is crucial for developing adaptive conservation strategies.

These frameworks and technologies combined offer a comprehensive approach to wildlife conservation, balancing ecological theory with practical management strategies. This research seeks to provide actionable insights that support long-term biodiversity preservation and address pressing conservation challenges by leveraging spatial data and remote sensing.

2.1.3 GIS in Wildlife Tracking

GIS technologies have significantly advanced wildlife monitoring and conservation efforts. Researchers can gain unprecedented insights into animal behavior, habitat use, and migration patterns by combining spatial data with modern tracking systems.

Jin et al. (2023) present an integrated animal tracking system that combines GPS technology with Unmanned Aerial Vehicles (UAVs). This system enables real-time tracking of animal movements, offering critical insights into their spatial ecology. UAVs complement GPS tracking by providing a bird's-eye view of an animal's surrounding environment, which is particularly useful in monitoring species in remote or inaccessible areas. By integrating these data into GIS, researchers can analyze movement patterns, identify habitat preferences, and detect environmental features influencing animal behavior. Jin et al. (2023) emphasize the efficiency of this system in reducing tracking costs while improving data accuracy, making it a valuable tool for large-scale wildlife studies.

In another case by Ramesh et al. (2021), they explored a cost-effective animal location tracking system for farm animals, utilizing Arduino and GPS modules. Arduino, an open-source microcontroller platform, enables the creation of low-cost, customizable tracking devices by integrating sensors and communication modules. Although developed for agricultural purposes, this system demonstrates the scalability and adaptability of GPS-based tracking for broader applications, including wildlife monitoring. Their study highlights how such technologies can monitor animal locations, mitigate human-wildlife conflict, and ensure efficient resource management. When integrated with GIS, the data collected by these systems can provide detailed spatial insights, aiding in developing habitat preservation and conflict resolution strategies.

2.2 Web Map Design for Animal Conservation

Web maps play a pivotal role in animal conservation by providing dynamic platforms for visualizing and analyzing critical wildlife data. These digital maps integrate GIS with interactive web technologies, enabling conservationists to monitor wildlife habitats, track migration patterns, and detect ecosystem changes. By layering data such as vegetation cover, migration routes, and human activities, web maps offer comprehensive insights for data-driven decision-making in habitat preservation and wildlife management.

2.2.1 A New Way to Map with Conservation Data

AgriLife Today (2024) explores innovative ways of using GIS and web mapping technologies for conservation efforts in “A New Way to Map with Conservation Data”. The focus is on a new method of mapping that integrates extensive conservation data into user-friendly web maps. This approach enhances conservationists' ability to visualize and manage data concerning endangered species, habitats under threat, and areas requiring immediate environmental protection.

The article highlights how these advanced mapping tools facilitate more informed decision-making through better data accessibility and enable real-time collaboration across various users. This is particularly important in conservation efforts, where timely information can lead to more effective responses to environmental threats. The integration of interactive web-based platforms allows users to manipulate data layers and customize views to suit specific project needs, thereby improving the efficiency of conservation planning and monitoring.

Furthermore, AgriLife Today (2024) discusses how these technologies are being adopted by conservation agencies to engage the public, educate communities about local and global conservation issues, and encourage more active participation in conservation initiatives. The article underlines the transformative potential of these mapping technologies in bringing about a more informed and collaborative approach to environmental stewardship.

2.2.2 Advanced Species Mapping for Conservation

Web-based platforms have significantly enhanced researchers' ability to visualize, analyze, and share wildlife data. These platforms bridge the gap between technical data processing and user-friendly interfaces, empowering a diverse audience of scientists, policymakers, and the public to engage with ecological information.

LaZerte et al. (2017) introduced feedr and animalnexus.ca, a paired R package and web application that enable the transformation and visualization of animal movement data from static monitoring stations. The feedr package processes large datasets, automating the cleaning and transformation of complex wildlife monitoring data. Meanwhile, the animalnexus.ca platform allows users to interact with these data through a web-based interface, providing visualizations that highlight movement patterns, site usage, and temporal trends. This dual approach is particularly advantageous for managing datasets generated by long-term monitoring programs, as it combines the computational power of R with an intuitive interface that broadens accessibility. LaZerte et al. (2017) emphasize the importance of user-focused design in ensuring that these tools are adequate for researchers and the public, making ecological insights actionable.

In another study by Dwyer et al. (2015) developed an open, web-based system specifically designed to analyze and share animal tracking data. The platform integrates multiple datasets, allowing researchers to analyze spatial and temporal patterns across various species and geographic scales. A key feature of their system is its ability to support collaboration among researchers and conservation practitioners, promoting transparency and encouraging multi-stakeholder involvement in data interpretation. The system also includes tools for filtering and visualizing movement data, enabling users to identify patterns such as migration corridors, hotspots of activity, and temporal shifts in habitat use. This approach aligns with modern conservation practices, prioritizing data sharing and collective decision-making to address complex ecological challenges.

2.3 Volunteered Geographic Information in Wildlife Conversation

VGI is an emerging data source that has transformed how wildlife conservation projects gather and utilize information on species distribution and movement. Platforms such as iNaturalist enabled millions of users to contribute geospatially referenced data on species observations, leading to massive datasets that would otherwise be unfeasible to collect through traditional fieldwork alone. However, integrating VGI into formal research frameworks brings about concerns about data quality, accuracy, and the uncertainty that arises from user-generated content. This section explores various aspects of VGI in wildlife conservation, focusing on managing uncertainty and integrating VGI with formal datasets.

2.3.1 Uncertainty-Aware Enrichment of Animal Movement Trajectories by VGI

One innovative approach to overcoming the challenges associated with VGI is presented by Hartmann et al. (2022) which demonstrates a method to enrich GPS-based animal movement data with VGI contributions, increasing the spatial and temporal scope of datasets used in movement ecology. The researchers highlight the potential of combining biologging data from GPS-collared animals with user-contributed data from platforms such as iNaturalist and eBird. The study develops an interactive system called BirdTrace (“VGIscience | Birdtrace,” n.d.), which facilitates the integration of VGI data with GPS-tracked bird movements while accounting for the inherent uncertainty in citizen-contributed data. The key innovation of this system is the uncertainty-aware framework that visually and statistically highlights the variability and potential inaccuracies in VGI contributions, such as species misidentification or incorrect geolocation. By implementing an uncertainty metric, researchers can assess the reliability of each VGI contribution before integrating it with more precise biologging data.

This approach directly relates to this project's goals of integrating VGI from iNaturalist with formal data collection and processing systems. The researchers in this case merged GPS data with VGI, aimed to incorporate new wildlife observation records with historical observation data while accounting for uncertainties in the VGI dataset. Additionally, the location-blurring techniques used in this project to protect endangered species align with the uncertainty-aware enrichment model, where sensitive or less specific data is handled carefully to avoid misuse. This hybrid approach, which combines the strengths of VGI and traditional data sources, can lead to more robust, actionable insights for wildlife conservation.

2.3.2 VGI and the Spatial-Discursive Construction of Nature

In the study by Astaburuaga et al. (2022), the authors investigate how maps and VGI not only serve as tools for geographic representation but also function as discursive instruments that shape human perceptions of nature. Focusing on the Patagonia-Aysén region in Chile, the study reveals that digital mapping and VGI contribute to constructing nature as "pristine," "untouched," and often commodified for tourism and conservation efforts. The research highlights that these tools are far from neutral; instead, they reflect and reinforce specific cultural and economic narratives, particularly within nature-based tourism.

Astaburuaga et al. (2022) argue that VGI contributes to the creation of a certain "spatial imaginary" of nature, often aligned with dominant discourses that frame natural spaces as commodities for human consumption, either for recreation or conservation. This understanding of nature can influence how society engages with and manages natural resources, including wildlife. The study emphasizes the importance of critically analyzing the power of spatial media, as these tools can perpetuate views of nature while marginalizing others.

When VGI is integrated into conservation mapping, as with wildlife monitoring systems like iNaturalist, it plays a dual role: providing valuable data for tracking species distributions while contributing to societal narratives about nature. Therefore, the implications of VGI for both scientific analysis and public engagement should be carefully considered to ensure that these maps foster a more nuanced understanding of biodiversity and ecological processes.

Furthermore, Astaburuaga et al. (2022) focused on the potential biases and uncertainties inherent in VGI data resonates with ongoing efforts to refine data collection methodologies for wildlife conservation. Enabling location-blurring techniques to protect endangered species helps address the ethical concerns of making sensitive spatial data publicly available.

2.3.3 Assuring the Quality of Volunteered Geographic Information

Goodchild and Li (2012) provide a foundational framework for assessing VGI quality, identifying key dimensions such as positional accuracy, attribute accuracy, completeness, consistency, and lineage. Their study highlights the unique challenges associated with ensuring data quality in crowdsourced geographic information due to the decentralized and voluntary nature of VGI contributions. Goodchild and Li (2012) propose a combination of intrinsic and extrinsic evaluation methods to mitigate quality issues. Intrinsic methods include analyzing the consistency and patterns within the VGI dataset itself. In contrast, extrinsic methods involve cross-referencing VGI with authoritative data sources, such as government or scientifically validated datasets.

A study by Flanagin and Metzger (2008) delves into the role of user reputation and validation mechanisms in enhancing VGI reliability. The authors argue that building user profiles based on expertise, experience, and accuracy history can help assess the reliability of individual contributions. For instance, experienced users with a track record of accurate submissions could be given higher credibility scores, and their data can be weighted more heavily in analyses. Many VGI platforms, including iNaturalist, have adopted peer review systems that allow other users to validate or question specific observations, thereby enhancing data reliability.

Other methods to assure VGI quality involve automated validation techniques. Haklay (2010) suggests using algorithms to detect outliers and unusual patterns in VGI submissions, which may indicate potential errors or inaccuracies. By employing machine learning models to flag data that diverges significantly from known distributions, automated systems can assist in maintaining a consistent level of quality across large datasets.

Despite these quality assurance efforts, the inherent uncertainty in VGI remains a challenge for conservation applications. Strategies such as cross-verifying VGI with remote sensing data, restricting observation updates to reduce potential threats (such as poaching), and employing peer validation methods aim to balance data accessibility with reliability. These measures not only enhance the quality of VGI but also address ethical considerations by minimizing the potential misuse of sensitive wildlife data.

Chapter 3: Methods

This chapter outlines the methodological framework employed in the development of this project. The methods described in this section are centered on data collection, processing, and integration within a GIS environment, as well as the design and deployment of the web application. Key processes include the gathering of wildlife data from iNaturalist, cleaning and refining the data to ensure accuracy and privacy, and visualizing the information using ArcGIS tools. Additionally, a survey for new wildlife observations was designed to facilitate user interaction. Each step of the methodology is aimed at producing an informative, user-friendly platform that supports wildlife conservation efforts.

3.1 Data Collection and Processing

The foundation of the "Historical Observation of Volunteered Geographic Information Data Web Map for Wildlife in Kenya" project is built upon robust data collection and processing methodologies, designed to ensure the accuracy, relevance, and usability of the spatial data used in this study. This section details the processes involved in sourcing, cleaning, and preparing the data for integration into a GIS web application.

3.1.1 Data Source: iNaturalist

iNaturalist is the key data source in the project, it is a public science platform that allows individuals to record, share, and discuss biodiversity observations. Founded in 2008, iNaturalist has grown into one of the largest databases for biodiversity data, with millions of contributions from users worldwide (iNaturalist.org 2025). The platform's main appeal lies in its ability to engage a wide community of users—ranging from professional scientists to hobbyists—in documenting species across the globe. Its open-source nature and ease of use have made it a valuable tool for both educational purposes and scientific research.

iNaturalist functions by allowing users to upload observations of plants and animals, which can include photographs, geographic coordinates, and temporal data. These observations are then either identified by the community or using artificial intelligence models. Once multiple users verify the observation, it can reach "research-grade" status, which means it can be used for scientific and conservation purposes. Many of these verified observations are then shared with global biodiversity databases, such as the Global Biodiversity Information Facility (GBIF), further extending their utility.

iNaturalist implements specific measures to handle endangered species data responsibly. Precise location data is automatically obscured for species flagged as threatened or endangered based on IUCN Red List (2024) criteria or regional conservation designations. Instead of sharing exact coordinates, iNaturalist replaces them with randomized points within a larger area to protect sensitive habitats from potential exploitation. Trusted researchers or organizations can access precise data after demonstrating a legitimate conservation need and agreeing to safeguard its use. These practices align with this project's approach to balancing data accessibility and species protection.

Understanding iNaturalist's capabilities and limitations is crucial to integrating it effectively as a primary data source for this project. To evaluate iNaturalist, a strengths, Weaknesses, opportunities, and Threats (SWOT) analysis (Table 1) was conducted. The SWOT analysis provides a comprehensive framework for evaluating iNaturalist's role in this project. By identifying its strengths, such as its large user base and multi-platform compatibility, the table highlights the aspects that make iNaturalist a valuable data source. At the same time, it considers weaknesses like limited filtering options and potential user confusion due to simplistic symbology. The analysis also identifies opportunities for growth, such as collaborations with conservation organizations, while acknowledging external threats, such as the challenge of securing consistent funding.

Table 1. SWOT Analysis for iNaturalist

<table>
<tr><td>Strength</td><td>Weakness</td></tr>
<tr><td>Large User Base: iNaturalist has a large community of users contributing observations and data.
Compatible with Multiple Platform: iNaturalist can be used on PC, tablets or phone. Data can be used across different platforms.</td><td>Data Orientation and visualization: iNaturalists does not support user to filter specific species on their web map, which leads to long loading time and distractions when visualizing data.
Simple Symbology: iNaturalist uses the simplest location icon to represent all data points and differ them with colors. But this leads to confusion since some colors are very similar.</td></tr>
<tr><td>Opportunity</td><td>Threats</td></tr>
<tr><td>Collaboration with Institutions: Partnering with academic institutions and conservation organizations can enhance data validation and research collaboration.
Public Awareness: Growing interest in biodiversity conservation globally offers opportunities to raise public awareness through the platform.</td><td>Funding and Sustainability: Ensuring consistent funding to maintain and develop the platform is crucial and can be a significant challenge.</td></tr>
</table>

Since the SWOT analysis aims to leverage strengths and opportunities while addressing weaknesses and threats, Table 2 outlines potential solutions to the weaknesses and threats identified in the previous analysis. These solutions aim to ensure iNaturalist's effectiveness and reliability as a tool for wildlife conservation while addressing its limitations in data visualization and sustainability.

Table 2. Potential Solutions to iNaturalist's Weakness and Threat

Solutions to Weakness	Solutions for Threat
• **Data Orientation and visualization:** This web application only focus on the four chosen taxa and allow users to turn on and off irrelevant layers as needed. • **Simple Symbology:** Cartoon style and more diverse colors are employed to differ different taxon group. Clustering allows users to observe where wildlife gathering directly.	• **Funding and Sustainability:** This project is developed completed based on personal interest and will never aim for any profitable target. This project is not aim for any profitable goals all time.

3.1.2 Data Extraction

Data extraction from iNaturalist was conducted using the platform's Application Programming Interface (API), which allows for efficient querying and retrieval of large datasets. Specific filters were applied to ensure that only relevant data was collected. These filters included:

- **Taxon Identification:** Only data classified under the four selected taxa (Amphibians, Mammals, Aves, and Reptiles) were extracted.

- **Geographical Boundaries:** Observations were limited to those within the political boundaries of Kenya.
- **Temporal Range:** The data was restricted to the period between January 1, 2010, and December 31, 2020.
- **Data Quality:** Only observations classified as "research grade" were included, ensuring a higher level of accuracy. Research grade observations on iNaturalist are those that have been confirmed by two or more users and include accurate geolocation data.

Table 3 provides a comprehensive overview of this project's data types, sources, and specific purposes. This table highlights the observation data extracted from iNaturalist and the supplementary vector data collected from credible sources to enhance the spatial analysis. These datasets form the foundation for analyzing wildlife patterns, understanding spatial distributions, and contextualizing the ecological and anthropogenic factors influencing the study area.

Table 3. Data Types and Purposes in the Project

Data (Count of Data)	Source	Description and Purpose
Amphibia Points (492) Aves Points (24215) Mammalia Points (17278) Reptilia Points(2912)	iNaturalist	Geocoded data with animal locations, time observed, images etc. To present historical locations of animals, and to analyze animal pattern through ArcGIS tool such as Hotspot Analysis.
Kenya Country Border	Africa Geoportal	Boundary of the study area
Kenya Wetlands and Protected Areas	National Geospatial-Intelligence Agency	Polygons of Kenya wetlands and protected areas
Kenya Roads and City Boundaries	OpenStreetMap	Outlines of main traffic roads and city boundaries.

3.2 Geographic Information System (GIS) Integration

ArcGIS Pro is employed in this project as the primary tool for visualizing wildlife observation data collected across Kenya. By leveraging the platform's advanced spatial analysis and mapping capabilities, the project transforms raw data from sources such as iNaturalist into interactive, informative maps that highlight species distributions and biodiversity patterns.

The data visualization process in ArcGIS Pro begins with the systematic import, cleaning, and management of spatial datasets. Once imported, the data is organized into customized layers representing different taxonomic groups and geographical areas. Using the platform's robust symbology and analysis tools, these layers are styled to create clear, user-friendly visual representations of wildlife distributions. The final step involves preparing the data for integration into web-based applications, allowing for interactive exploration by researchers, policymakers, and the public. This section details the procedures undertaken in ArcGIS Pro, from data management to the creation of dynamic, web-ready maps that support conservation efforts.

3.2.1 Data Import

The integration of GIS data begins with importing the raw datasets from various sources, including iNaturalist VGI data and map elements such as Kenya boundaries. Effective data management is essential to ensure that the imported data is correctly formatted, stored, and organized for subsequent analysis and visualization. This section outlines the procedures followed for importing data into the GIS environment, managing the database, and organizing data layers to maintain consistency and usability.

The wildlife observation data used in this project was sourced from iNaturalist, provided in s CSV. ArcGIS Pro allows for seamless import of these formats, converting them into GIS-readable data structures that can be further processed and visualized.

- **CSV Import**: CSV files containing wildlife observation data were imported into ArcGIS Pro using the XY Table to Point function as shown in Figure 2. This feature converts tabular data with latitude and longitude values into point feature classes, enabling geographic visualization. Each record represents a unique wildlife observation, with attributes such as species name, timestamp, and observer details.

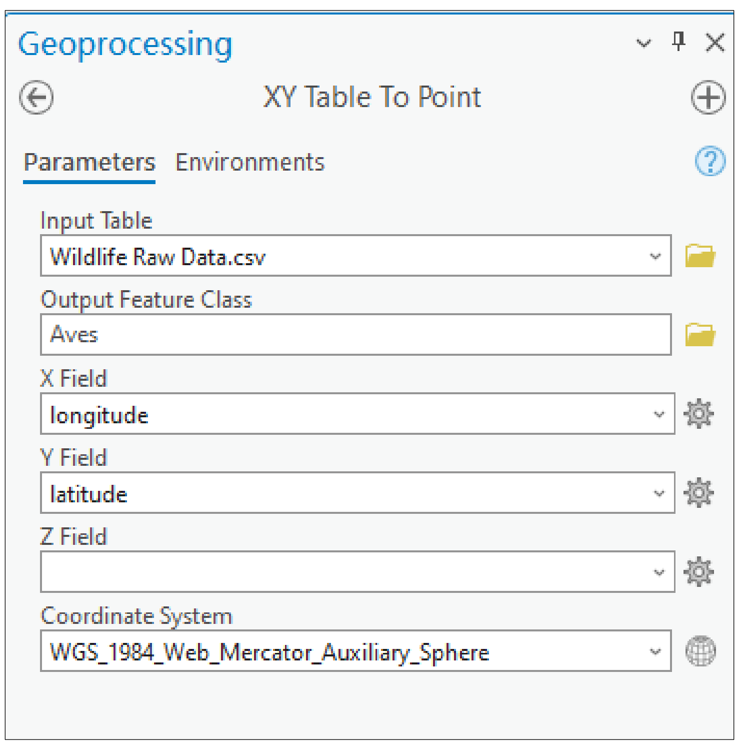


Figure 2. XY Table to Points Tool

- **Vector Data (Basemap) Import**: The country boundary of Kenya was imported from the Esri Africa Geoportal (2023). The roads and city locations were extracted from OpenStreetMap. After comparing and checking the background information between different datasets, most recently updated credential datasets were imported to enrich the basemap.

3.2.2 Data Cleaning

Upon importing, the data underwent a rigorous cleaning and pre-processing phase to prepare it for analysis and integration into the GIS. This process involved several steps:

- **Duplication or Blank Data Removal:** Entries were flagged as duplicates if they shared identical taxon identification, timestamp, and geographic coordinates. These records were then systematically compared and merged or removed to maintain a unique set of observations for each observation. For instance, duplicate reports of the same animal in the same location and time window were consolidated into a single record. Entries missing key attributes such as geolocation, taxon classification, or timestamp were considered incomplete and were removed from the dataset. In cases where taxonomic data or timestamps were present but lacked geographic coordinates, additional validation was attempted via referencing other records, but if unresolved, these entries were discarded.

- **Geolocation Accuracy:** Each geographic entry was checked for plausible values in terms of latitude and longitude, ensuring that all points fell within the expected boundaries of the study area (Kenya). Points located outside the region or placed obviously incorrectly (e.g. Crocodile in the desert) were removed. All the data are reprojected into WGS 84.

3.2.3 Hotspot Analysis

Hotspot analysis was employed as a key method for identifying areas with high concentrations of wildlife observations across the study region. This technique utilizes GIS tools to evaluate spatial clustering patterns within the historical dataset (2010–2020), highlighting critical regions for wildlife conservation. The Getis-Ord Gi* statistic was applied to detect statistically significant clusters of high and low wildlife densities, revealing spatial trends that inform conservation strategies. These hotspots provide users data-driven insights into biodiversity trends (Garrah 2015).

3.2.4 Data Management

Once the data was successfully imported and cleaned, it was stored and managed within a geodatabase to streamline data handling and enhance performance. The geodatabase acts as a centralized repository for the project's spatial data, allowing for efficient querying, updating, and managing of datasets.

- **Layered Structure**: Separate layers were created from the raw wildlife dataset for each taxonomic group (Amphibians, Mammals, Aves, and Reptiles), ensuring that the data could be visualized and analyzed individually or in combination. Each layer contains the spatial locations of the respective taxon's observations along with the associated attributes (e.g., species name, observation date). Meanwhile, other map contents such as basemap content and hotspot analysis were grouped individually for better organization
- **Geodatabase**: The use of a **file geodatabase** was chosen for this project due to its ability to store large datasets, maintain relationships between spatial and non-spatial data, and provide the necessary scalability for future updates. The geodatabase contains feature classes for spatial data and **tables** for non-spatial attributes, such as observer details or metadata on each observation.
- **Local Backup**: To keep the web application functional and avoid losing connection to online data, a backup database and ArcGIS Pro Package were created on a personal device and ready to transfer to another account in the future if needed.

3.3 Experience Builder

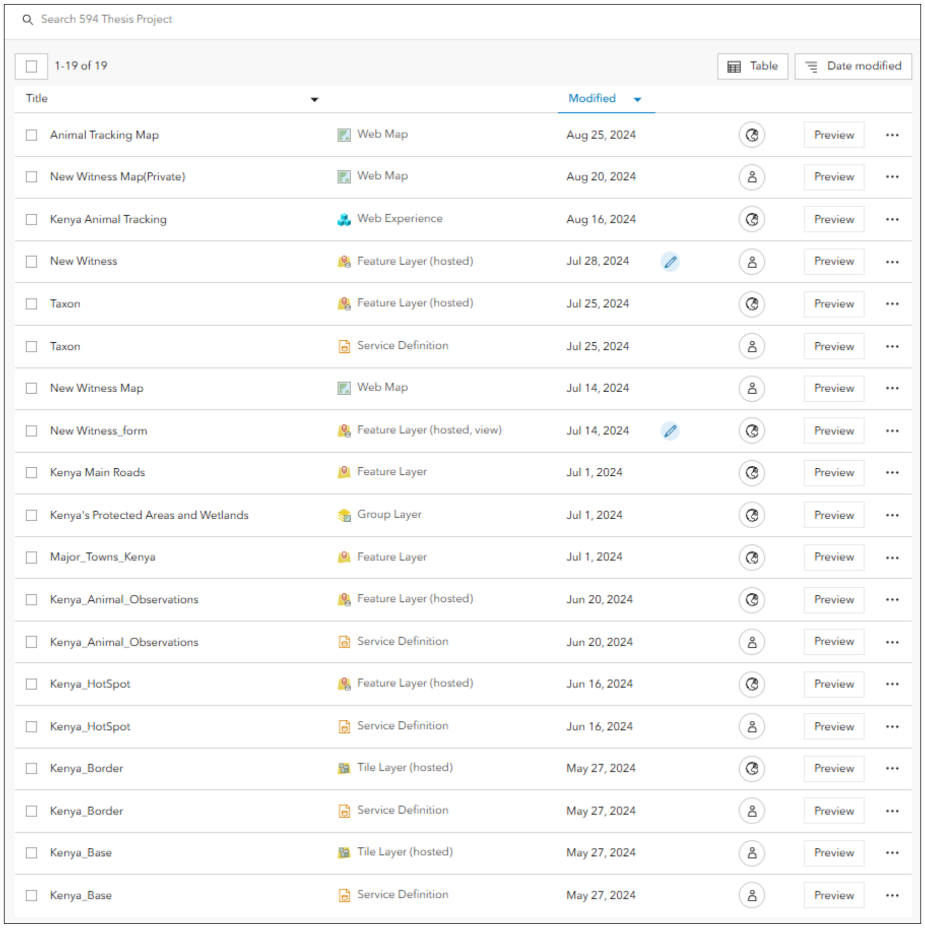
As part of the data visualization process, ArcGIS Experience Builder, Enterprise Version (2024), was employed to create an interactive web-based platform that allows users to explore wildlife observation data. ArcGIS Experience Builder is a flexible tool that enables the development of custom web applications with dynamic maps, rich user interfaces, and interactive features. This section outlines the steps including data exporting, web map design and implementation using ArcGIS Experience Builder, focusing on user interaction, layout design, and functionality.

3.3.1 Data Export to ArcGIS Online

Before exporting data from ArcGIS Pro to ArcGIS Online, data preparation within ArcGIS Pro involves ensuring that all layers are correctly structured, symbolized, and contain accurate geospatial references. This process is described within the previous sections.

Following data preparation, the next step is publishing the data as a web layer. In ArcGIS Pro, users can right-click the target layer, browse the "Share" tab, and choose "Publish Web Layer." This process involves configuring several settings, such as naming the web layer, adding descriptions, and defining layer types. Users also define who can access the layer through sharing settings, choosing between public access, restricted organizational access, or group-specific access.

Once the web layer is published to ArcGIS Online, the next step is to verify and group the data. This verification process ensures that all data attributes, symbology, and pop-ups have been correctly transferred and appear as intended. By navigating to the "Content" tab in ArcGIS Online, users can review and interact with the published web layer to ensure that it behaves as expected in the online environment. In the end, a folder called "594 Thesis Project" is created as shown in Figure 3, which holds all the data employed in this project.



Search 594 Thesis Project

1-19 of 19 Table Date modified

Title		Modified			
Animal Tracking Map	Web Map	Aug 25, 2024		Preview	···
New Witness Map(Private)	Web Map	Aug 20, 2024		Preview	···
Kenya Animal Tracking	Web Experience	Aug 16, 2024		Preview	···
New Witness	Feature Layer (hosted)	Jul 28, 2024		Preview	···
Taxon	Feature Layer (hosted)	Jul 25, 2024		Preview	···
Taxon	Service Definition	Jul 25, 2024		Preview	···
New Witness Map	Web Map	Jul 14, 2024		Preview	···
New Witness_form	Feature Layer (hosted, view)	Jul 14, 2024		Preview	···
Kenya Main Roads	Feature Layer	Jul 1, 2024		Preview	···
Kenya's Protected Areas and Wetlands	Group Layer	Jul 1, 2024		Preview	···
Major_Towns_Kenya	Feature Layer	Jul 1, 2024		Preview	···
Kenya_Animal_Observations	Feature Layer (hosted)	Jun 20, 2024		Preview	···
Kenya_Animal_Observations	Service Definition	Jun 20, 2024		Preview	···
Kenya_HotSpot	Feature Layer (hosted)	Jun 16, 2024		Preview	···
Kenya_HotSpot	Service Definition	Jun 16, 2024		Preview	···
Kenya_Border	Tile Layer (hosted)	May 27, 2024		Preview	···
Kenya_Border	Service Definition	May 27, 2024		Preview	···
Kenya_Base	Tile Layer (hosted)	May 27, 2024		Preview	···
Kenya_Base	Service Definition	May 27, 2024		Preview	···

Figure 3 ArcGIS Online Layer Management

3.3.2 Web Map Design

This section focuses on refining the map content after data is exported from ArcGIS Pro to ArcGIS Online. The first step is the selection and customization of a basemap. The basemap provides the geographical context for the wildlife data. A simple, clean basemap is essential to avoid overwhelming users with excessive information. In this project, a light gray canvas basemap was chosen for its minimalistic design as shown in Figure 4, allowing wildlife layers to stand out.

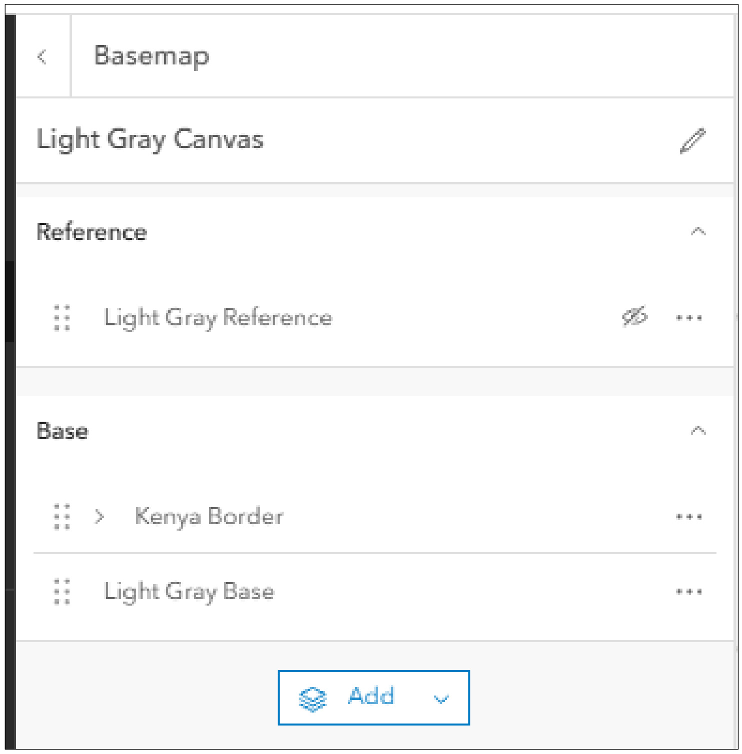


Figure 4. Basemap Editing

Once the basemap design is finished, the next step is to add the data layers exported for ArcGIS Pro to the map. By clicking “Add” in the layer tab, at the bottom of Figure 5, and users can choose the source of data. After navigating to “My Content,” all the related data are added.

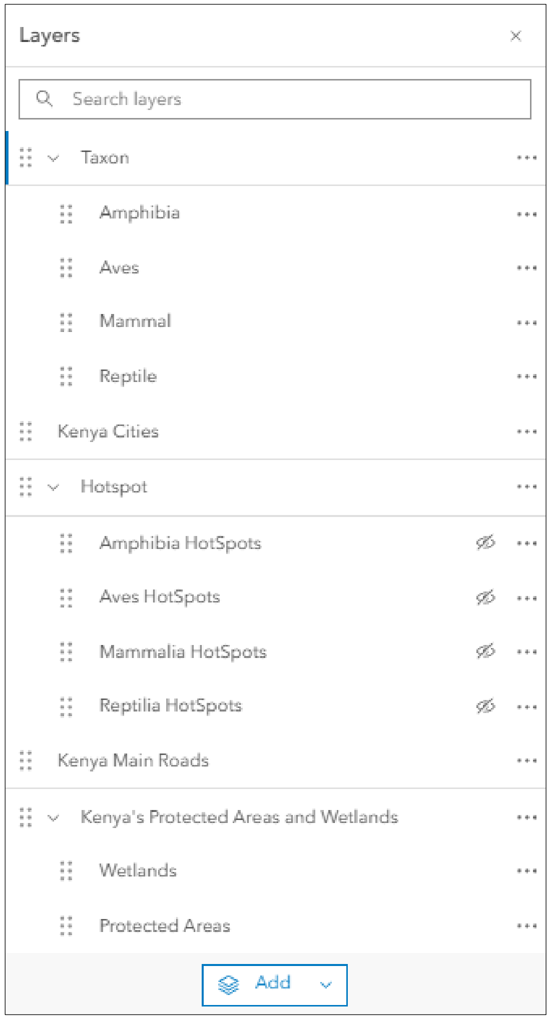


Figure 5. Adding Map Contents

With many data points, particularly for taxa and many observations, the clustering function in Figure 6 can significantly improve the visual effect. Clustering groups observations geographically close into a single cluster, with a number indicating the count of observations in that area. This reduces visual clutter and improves the map's readability, especially when zoomed out. As users zoom in, the clusters break apart into individual points, allowing for detailed exploration of specific observations.

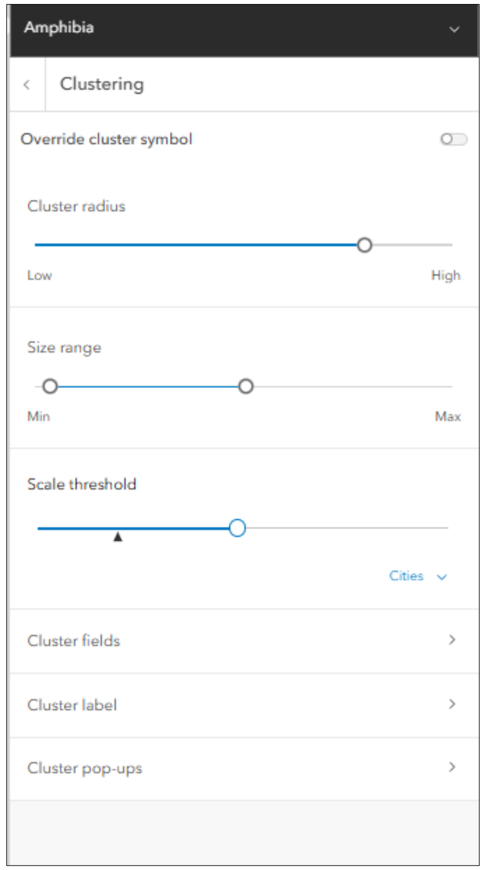


Figure 6. Data Clustering Setting

In the meantime, the original pop-up windows contain too much irrelevant information, such as the name of the users who created the observation. Therefore, as shown in Figure 7, pop-up windows are configured only to show key attributes like species information, observation date, and an image (if available). These pop-ups provide an interactive way for users to access additional details about each observation. The pop-up window’s design ensures the information is well-structured, visually appealing, and easy to navigate. Figure 8 provides an example of pop-up window of cheetah.

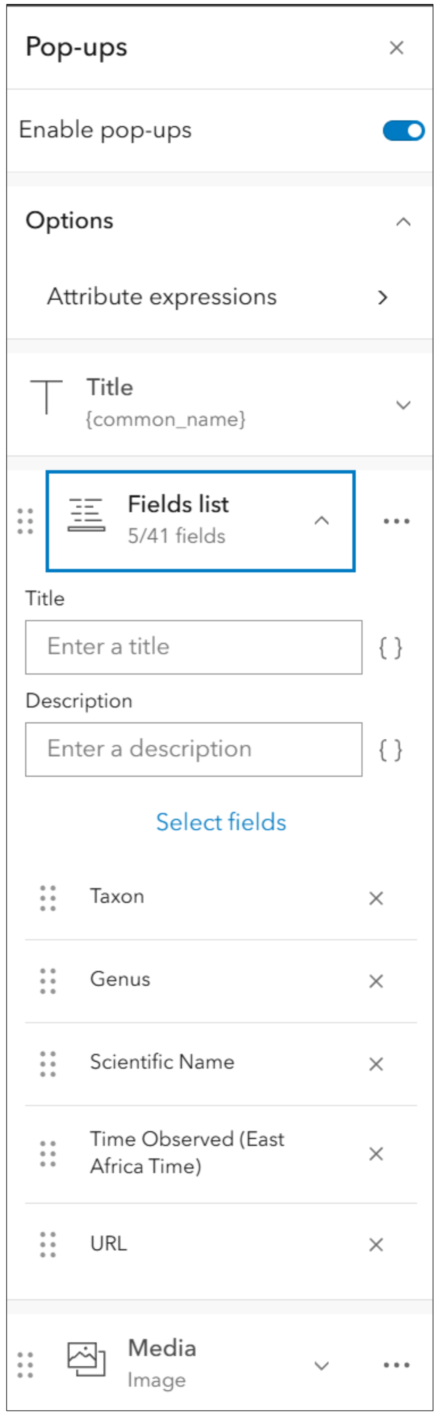


Figure 7. Pop-ups Setting

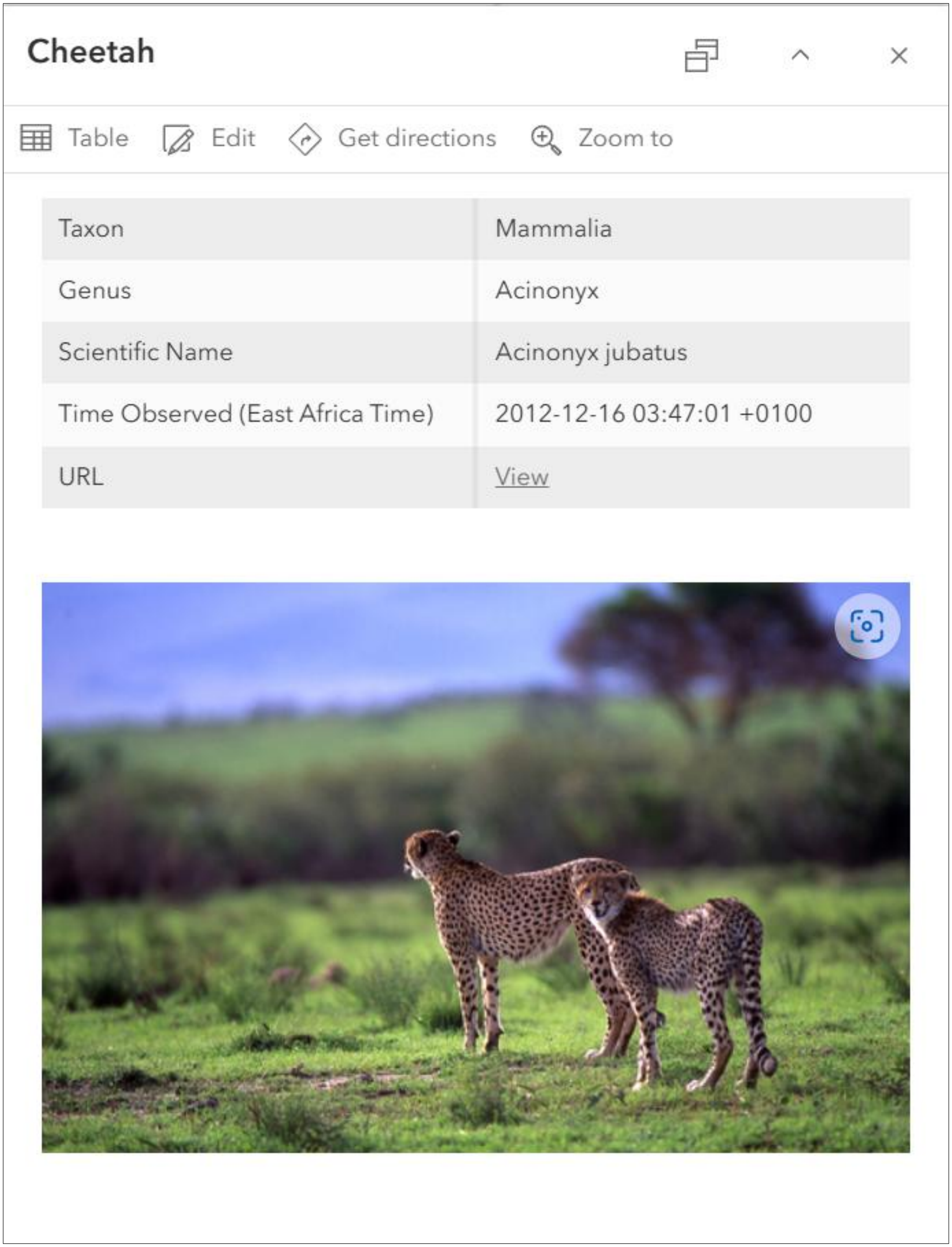


Figure 8. Example of a Pop-up Window

A time slider is added to the map (Figure 9). This tool allows users to filter observations by date, providing insights into temporal patterns in wildlife observations across the 2010-2020 dataset. Users can explore how wildlife distributions have changed over time, which can be valuable and efficient for researchers and conservationists. The default temporal range is set to be three months, a season-long for effective observation, starting from January 1st, 2010.

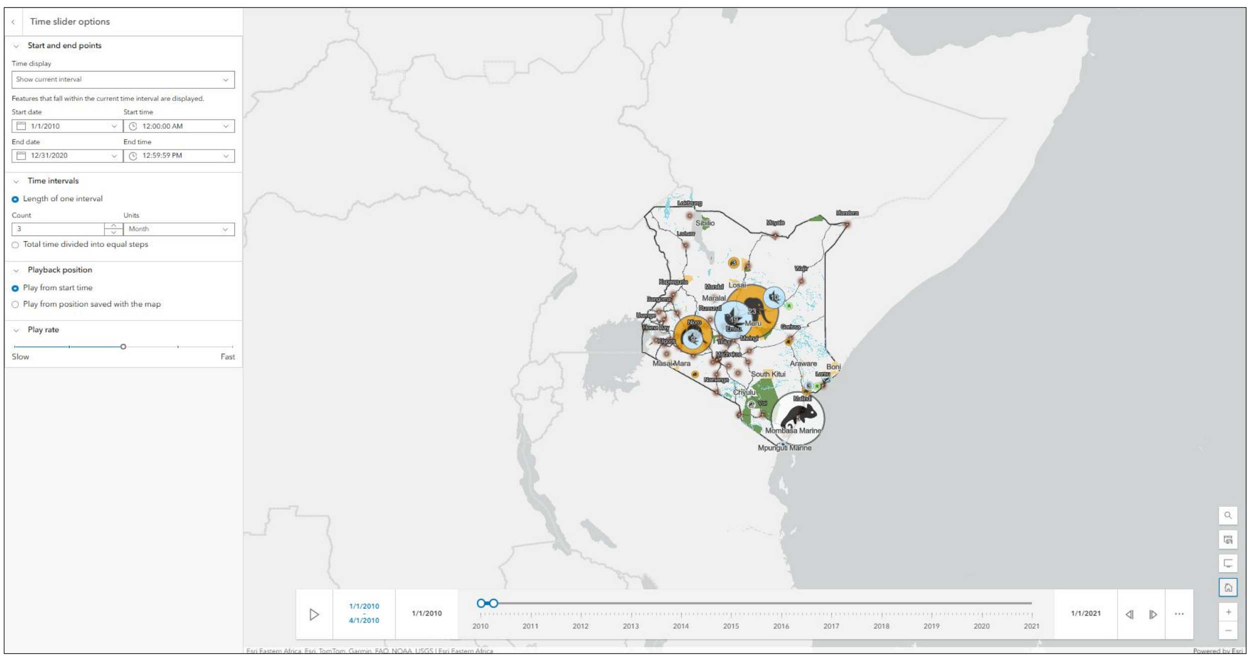


Figure 9. Time Slider Setting

3.3.3 Integration in Experience Builder

The ArcGIS Experience Builder is one of the most important elements in this project. It not only holds the wildlife web map but also provides multiple widgets that enhance public interactivity. The layout of the Experience Builder is designed to make the map the central focus of the application, ensuring users can easily interact with the wildlife data.

Different layout sizes were employed to ensure that the application adapts seamlessly to different screen sizes, from desktop (Figure 10) to mobile devices (Figure 11).

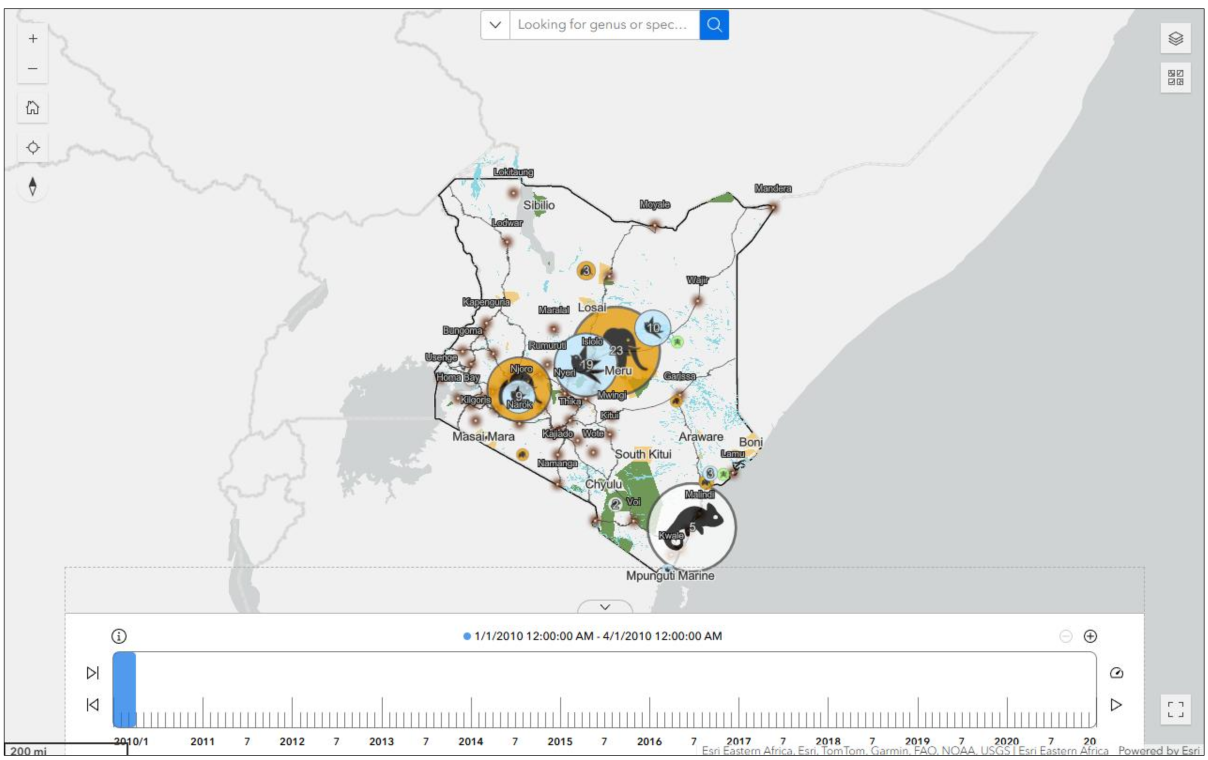


Figure 10. Experience Builder Map Appearance

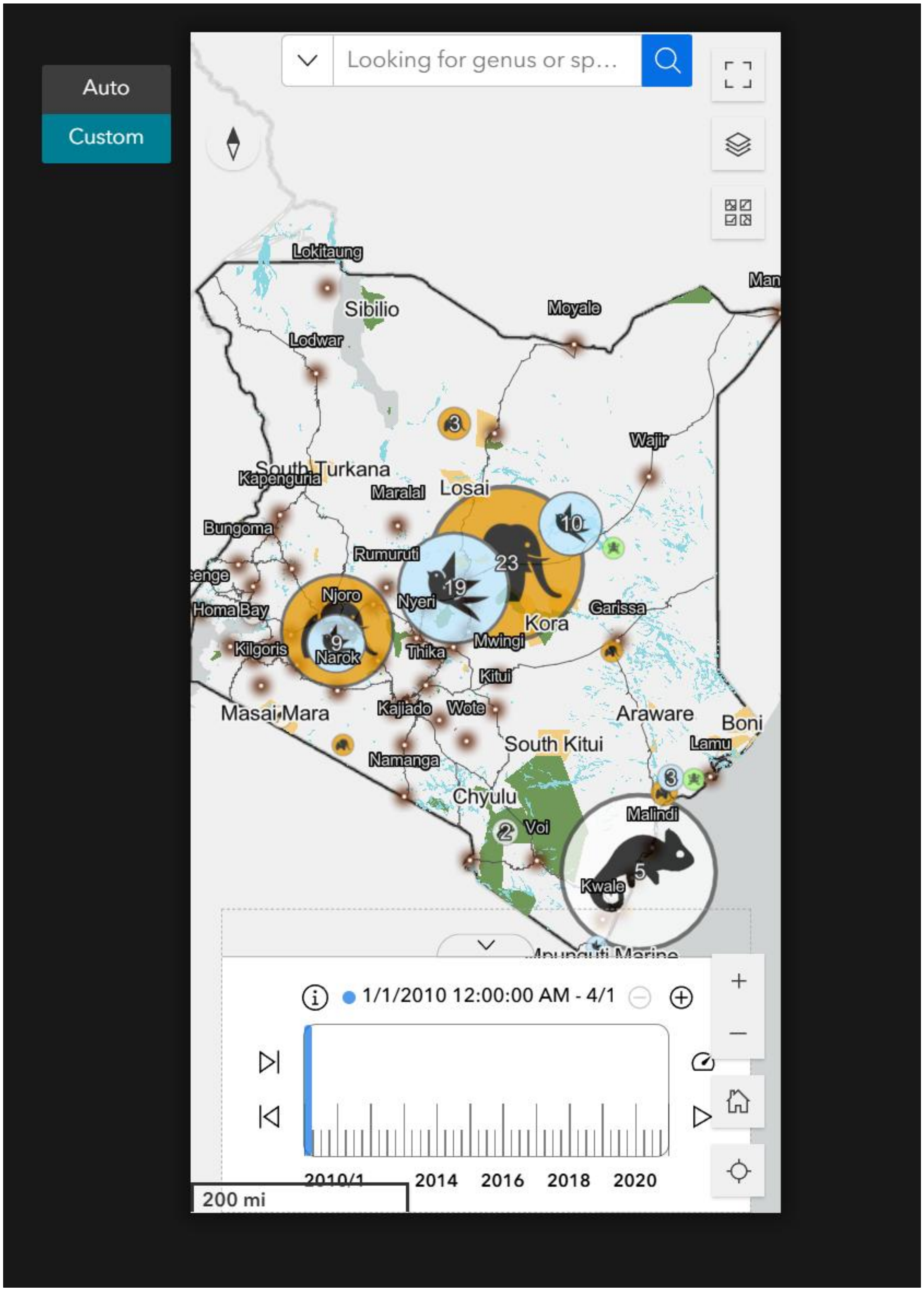


Figure 11. Map Content Appearance on Small Screen Device

A search box widget is integrated into the Experience Builder to enable users to locate specific regions or species within the map. This widget supports filtering by taxonomic groups or periods, allowing users to tailor their exploration and focus on relevant data. Figure 12 illustrates the back-end configuration view of the search box widget. This view displays the setup options available to the developer, such as selecting data sources, enabling filtering for specific taxa (e.g., Amphibia, Aves, Mammal, Reptile), and configuring search fields like genus, common name, scientific name, and species guess

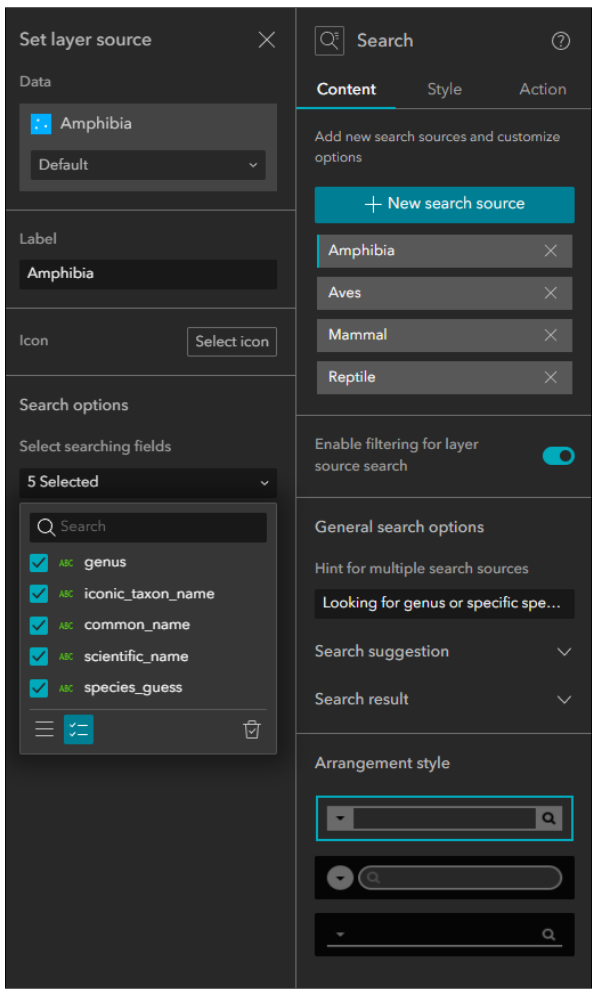


Figure 12. Search Box Design

3.4 New Observation Report

The new observation report feature allows users to contribute wildlife documentation through a structured data submission form built using Esri Survey123 (Figure 13). This tool enables the collection of valuable wildlife data, including species identification, geographic location, observation time, and optional photographic evidence. However, to prevent the misuse of sensitive wildlife location data, such as for poaching, these observations are not integrated into the web map in real time. Instead, all submitted observations are securely stored and reviewed periodically to ensure data accuracy and conservation integrity. Unlike conventional citizen science platforms, where data is immediately accessible, this project follows a scheduled update cycle to protect endangered species and minimize ecological risks. New observations will be incorporated into the public dataset every five years, aligning with the project's commitment to responsible data sharing.

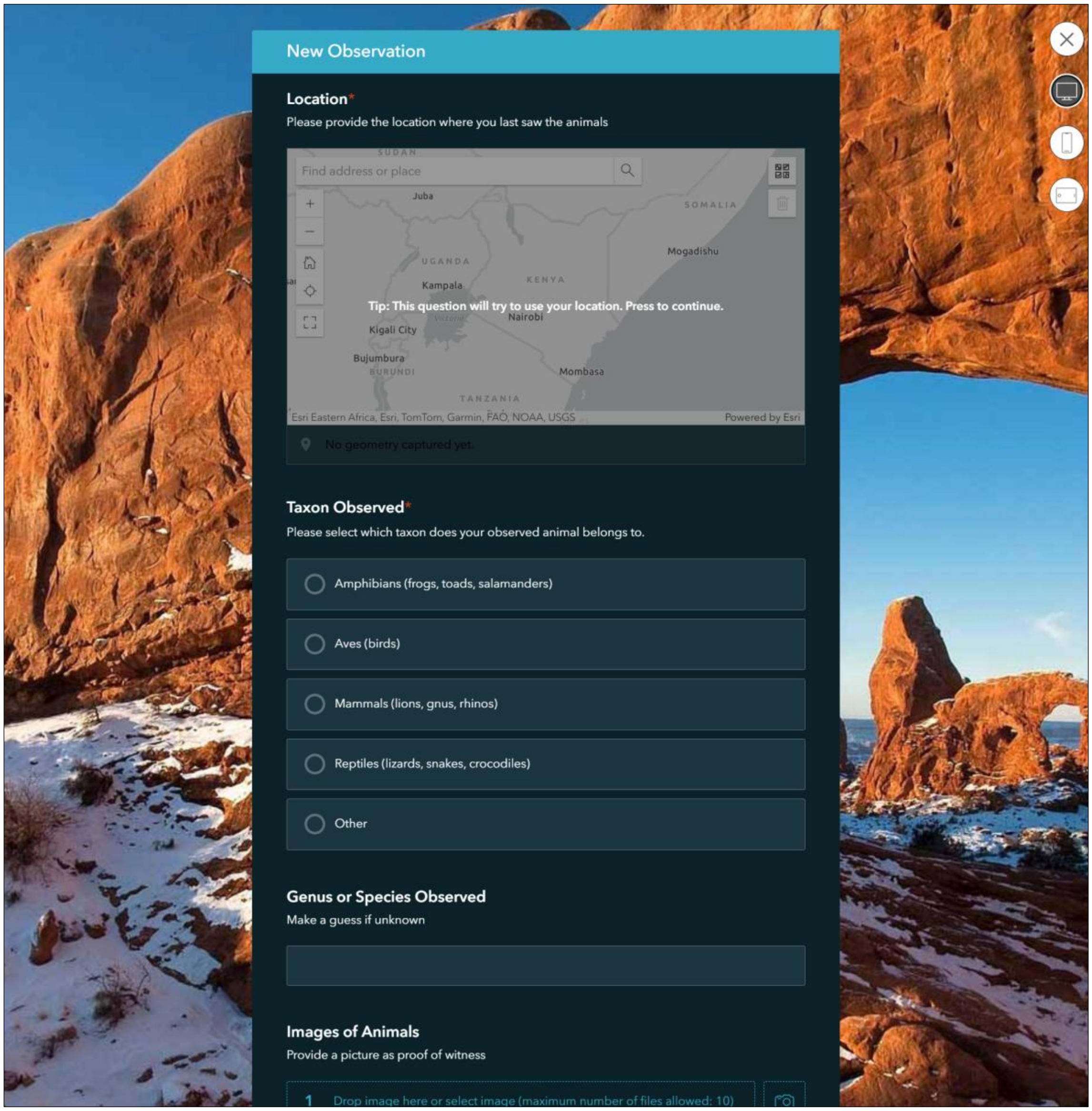


Figure 13. Esri Survey123 Form Appearance

The structure of the Survey123 form is divided into several key fields, each carefully designed to gather critical information related to the wildlife observations. These fields are required or optional based on the nature of the data needed, with clear prompts to guide users through the process. Figure 14 shows the creation panel of the Esri Survey123.

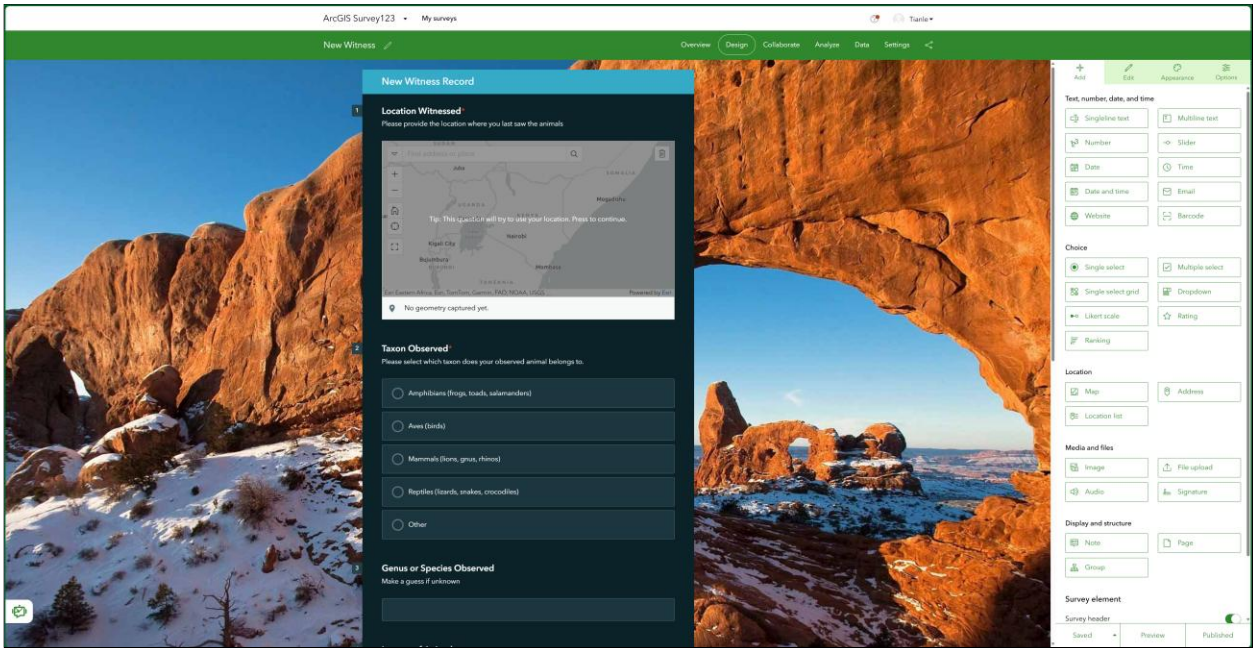


Figure 14. Esri Survey123 Creation

The survey includes the following questions:

- **Location of Observation**: The survey form includes a map-based geolocation feature to capture precise geographic data for each observation. By default, the form automatically records the user's location using their device's GPS. However, users can manually adjust their location by dragging the point on an interactive map. This flexibility ensures that observations are accurately geolocated, even in areas where GPS signals may be weak or imprecise. Allowing users to refine their location improves data quality, especially in regions with low locational accuracy or when observations are made near spatial boundaries. This is a required question.

- **Taxon Observed**: This field provides users with a dropdown list of taxa, categorized into the relevant taxonomic groups (Amphibians, Mammals, Aves, and Reptiles). This is a required question.
- **Genus Or Species Observed**: This field encourages users to identify the specific species they reported. However, users can also guess if they are unable to identify the specific creature. This is an optional question.
- **Date and Time of Observation**: Users are required to input the date and time of their wildlife observation. This information helps in tracking temporal patterns in wildlife activity and understanding seasonal or diurnal behavior. This is a required question.
- **Notes**: An optional field allows users to provide additional context to their observation, such as the behavior of the animal, the environment when they observed the animal, or any notable conditions (e.g., weather). This qualitative data can offer further insights into the wildlife behaviors being observed.
- **Media Attachments**: Users are encouraged to upload media files such as photos or videos of the observed species. This visual evidence aids in the verification process, especially for observations of rare or endangered species.
- **Contact Information**: Optional fields regarding phone number and email are provided if users expect further conversation.

3.5 Web Framework

The Historical Kenya Wildlife Observation Map web application serves as an interactive platform for observation, reporting, and visualizing wildlife observations in Kenya. This section outlines the design and development of the web frame, focusing on the integration of wildlife data with a user-friendly, intuitive interface. The primary objective of the web frame is to facilitate public participation while ensuring that data is responsibly accessed and used.

The web frame was designed using a combination of HTML and CSS and divided into several sections, including a header with additional resources links, an iframe container for viewing the ArcGIS-based wildlife map, a link for submitting new wildlife reports, and a footer with disclaimers and attribution.

3.5.1 Welcome Message Pop-up

The pop-up window of the welcome message is the first interactive function that provides users with an introductory message and a legal disclaimer. This message in Figure 15 ensures that users understand the purpose of the site, the terms of use, and the importance of responsible behavior, particularly given the sensitive nature of the wildlife data.

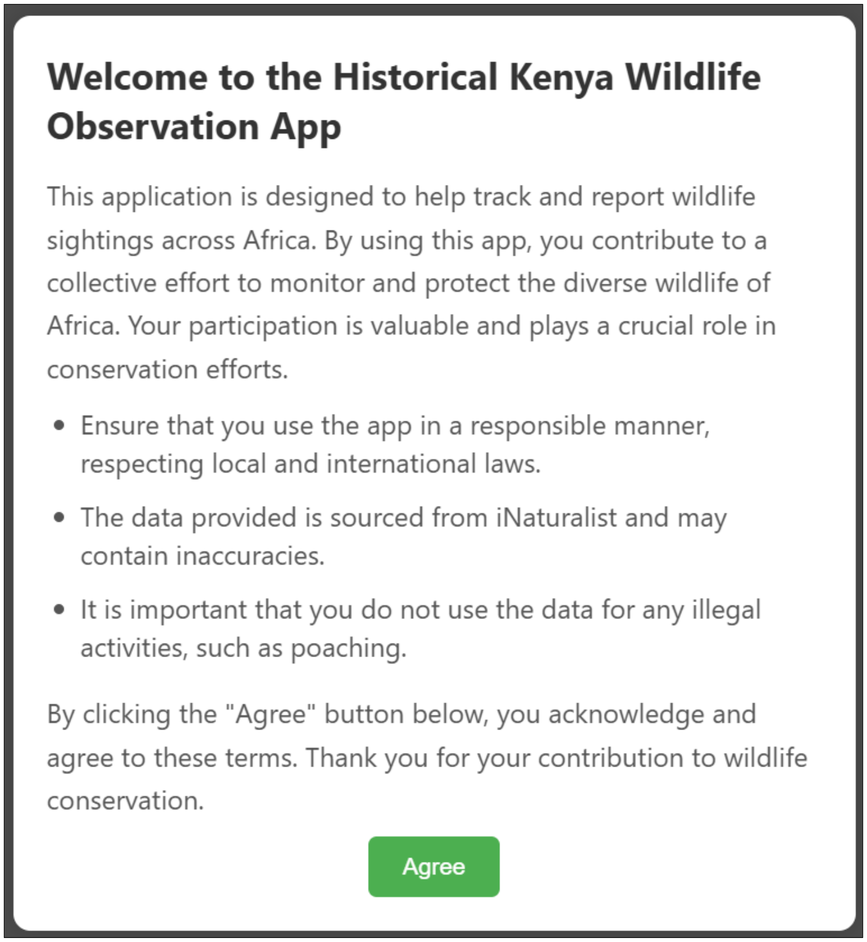


Figure 15. Welcome Message Pop-up

The welcome message pop-up is implemented using a modal window (Figure 16), and it is triggered automatically when the page loads and displays a message that welcomes the user to the web application, followed by a brief introduction and legal disclaimer. Users must click the "Agree" button to close the pop-up and acknowledge the terms, thus ensuring they understand the usage restrictions before interacting with the site.

```html
<div id="disclaimerModal" class="modal">
    <div class="modal-content">
        <h2>Welcome to the Historical African Wildlife Siting App</h2>
        <p>This application is designed to help track and report wildlife sightings acros
        <ul>
            <li>Ensure that you use the app in a responsible manner, respecting local and
            <li>The data provided is sourced from iNaturalist and may contain inaccuracie
            <li>It is important that you do not use the data for any illegal activities,
        </ul>
        <p>By clicking the "Agree" button below, you acknowledge and agree to these terms
        <button class="close-btn" onclick="closeModal('disclaimerModal')">Agree</button>
    </div>
</div>
```

Figure 16. HTML Expression for the Pop-Up

When the page finishes loading, the openModal() function is called, which sets the modal’s display property to flex, making it visible to the user. The modal remains visible until the user clicks the "Agree" button. When the user clicks the "Agree" button, the closeModal() function is triggered, setting the modal’s display back to none, effectively hiding the modal and allowing the user to proceed to the main content (Figure 17).

```javascript
function openModal(modalId) {
    document.getElementById(modalId).style.display = 'flex';
}

function closeModal(modalId) {
    document.getElementById(modalId).style.display = 'none';
}

window.onload = function() {
    openModal('disclaimerModal');
};
```

Figure 17. JavaScript Expression for the Pop-up Modal

In Figure 18, the modal is centered using Flexbox properties (justify-content: center; align-items: center), which vertically and horizontally centers the content within the viewport. This layout ensures that the modal remains central and responsive across all screen sizes.

```css
/* Welcome Message */
.modal {
    display: none;
    position: fixed;
    z-index: 2000;
    left: 0;
    top: 0;
    width: 100%;
    height: 100%;
    overflow: auto;
    background-color: rgba(0, 0, 0, 0.7);
    justify-content: center;
    align-items: center;
    padding: 20px;
}

.modal-content {
    background-color: white;
    padding: 20px;
    border-radius: 10px;
    width: 100%;
    max-width: 500px;
    text-align: left;
    box-shadow: 0px 0px 15px rgba(0, 0, 0, 0.2);
}

.modal-content h2 {
    margin-bottom: 15px;
    font-size: 22px;
    font-weight: bold;
    color: #333;
}

.modal-content p {
    margin-bottom: 10px;
    line-height: 1.6;
    color: #555;
}

.modal-content ul {
    margin-bottom: 15px;
    padding-left: 20px;
}

.modal-content ul li {
    margin-bottom: 10px;
    line-height: 1.4;
    color: #555;
}

.close-btn {
    background-color: #4CAF50;
    color: white;
    padding: 10px 20px;
    border: none;
    border-radius: 5px;
    cursor: pointer;
    font-size: 14px;
    display: block;
    margin: 0 auto;
    transition: background-color 0.3s;
}

.close-btn:hover {
    background-color: #45a049;
}
```

Figure 18. CSS Expression for the Welcome Message

The "Agree" button is styled to align with the overall theme of the web application, using the same green color scheme (background-color: #4CAF50) as the header and other buttons. The button is centrally aligned and provides a clear call to action for users to acknowledge the disclaimer before they proceed to use the application. A hover effect (background-color: #45a049) is added to notice the users they have selected the button.

3.5.2 Header, Additional Resources Bar and Help Icon

The header (Figure 19) is a critical part of the web page as it establishes the identity of the application and provides navigational elements to guide users through the site. It plays a central role in maintaining a professional look and ensures that key information is easily accessible to the user from the moment they land on the page.

Figure 19. Header Appearance

- Header

The header is designed using the HTML <header> element (Figure 20), which semantically defines the introductory section of the web page. It houses the application title, additional resources links, and a help icon (question mark button). The layout of the header is controlled through CSS Flexbox to ensure that the elements align and respond to different screen sizes while maintaining a clean and structured appearance.

```
<body>
    <header>
        <div class="title-container">
            <h1>Historical African Wildlife Siting Map</h1>
        </div>
        <button class="question-mark" onclick="showModal('howItWorksModal')">?</button>
    </header>

    <div class="container">
        <div class="tabs-container">
            <h2>Observation Record 2010-2020</h2>
            <div class="tabs">
                <a href="https://www.brilliant-africa.com/kenya/wildlife" target="_blank">Wildlife in Kenya</a>
                <a href="https://api.worldanimalprotection.org/country/kenya" target="_blank">Animal Protection</a>
                <a href="https://www.kws.go.ke" target="_blank">Wildlife Service</a>
                <a href="https://www.sheldrickwildlifetrust.org/projects/anti-poaching" target="_blank">Anti-Poaching</a>
            </div>
        </div>
```

Figure 20. HTML Expression for the Header and Part of Elements in the Container

The code in figure 21 shows the styling setting of the header. The title "Historical Kenya Wildlife Observation Map" is centered using the Flexbox justify-content: center property, which places the title evenly across the available space. This ensures that regardless of screen size, the title is always placed at the center of the header.

```
<!DOCTYPE html>
<html lang="en">
<head>
    <meta charset="UTF-8">
    <meta name="viewport" content="width=device-width, initial-scale=1.0">
    <meta name="description" content="Track and report wildlife sightings in Africa.">
    <title>Historical African Wildlife Siting Map</title>
    <style>
        * {
            margin: 0;
            padding: 0;
            box-sizing: border-box;
        }

        html, body {
            height: 100%;
            overflow: hidden;
        }

        body {
            font-family: 'Segoe UI', Tahoma, Geneva, Verdana, sans-serif;
            background-color: #f4f4f4;
            color: #333;
            display: flex;
            flex-direction: column;
        }

        /* Header*/
        header {
            background-color: #4CAF50;
            color: white;
            padding: 1rem;
            display: flex;
            justify-content: space-between;
            align-items: center;
            position: relative;
            z-index: 1000;
            box-shadow: 0px 4px 6px rgba(0, 0, 0, 0.1);
            flex-wrap: wrap;
        }

        .title-container {
            flex: 1;
            text-align: center;
            font-size: 1.5rem;
            font-weight: bold;
        }
```

Figure 21. CSS Expression for the Header

The title is styled with a font size of 1.5rem and bold text (font-weight: bold), making it stand out against the background while remaining accessible and readable across devices.

The header uses a green background (#4CAF50) to create a visually pleasing look that aligns with environmental and wildlife themes. This also helps distinguish the header from the rest of the page content. The text within the header is white (color: white), providing sharp contrast and enhancing readability.

- Additional Resources

The additional resources links are located on the right side just below the title in the header, contains links to external resources and relevant information. These links allow users to quickly access wildlife-related websites, such as Wildlife in Kenya, Animal Protection, and Anti-Poaching.

Additional Resources Link Styling: Each link is styled as a block-level element with padding (padding: 8px 12px) and a background color of dark gray (#333). The links change color when hovered over (background-color: #555), providing visual feedback to users and encouraging interaction (Figure 22). The hover effect is achieved using the CSS :hover pseudo-class, which smoothly transitions the background color, enhancing the overall user experience.

```
/* Navigation Bar*/
.navbar {
    display: flex;
    gap: 10px;
    flex-wrap: wrap;
    justify-content: center;
    padding-top: 10px;
}

.navbar a {
    color: white;
    text-decoration: none;
    padding: 8px 12px;
    background-color: #333;
    border-radius: 5px;
    transition: background-color 0.3s;
    font-size: 14px;
}

.navbar a:hover {
    background-color: #555;
}
```

Figure 22. CSS Expression for Additional Resources Bar

The additional resources bar is responsive, adjusting its layout depending on the screen size. For larger screens, the links are displayed side-by-side in a horizontal row. On smaller screens, the Flexbox flex-wrap property ensures the links stack vertically or wrap, preventing overlap and maintaining usability on mobile devices.

- Help Icon (Question Mark)

The help icon is positioned using absolute positioning as shown in Figure 23 (position: absolute; right: 20px; top: 50%;) to ensure it remains at the top-right corner of the header, regardless of the screen size. The transform: translateY(-50%) property is used to vertically center the icon relative to the height of the header.

```css
/* Question Mark*/
.question-mark {
    position: absolute;
    right: 20px;
    top: 50%;
    transform: translateY(-50%);
    font-size: 20px;
    cursor: pointer;
    color: white;
    background-color: #000;
    border: 2px solid white;
    border-radius: 50%;
    width: 35px;
    height: 35px;
    display: flex;
    justify-content: center;
    align-items: center;
    transition: background-color 0.3s;
}

.question-mark:hover {
    background-color: #333;
}

.question-mark:hover::after {
    content: "How it works?";
    position: absolute;
    top: 50%;
    left: -130px;
    transform: translateY(-50%);
    background-color: #555;
    color: white;
    padding: 5px 10px;
    border-radius: 5px;
    white-space: nowrap;
    font-size: 12px;
}
```

Figure 23. CSS Expression for the Help Icon

When hovered over, the button displays a tooltip with the message "How it works?". This is implemented using the CSS ::after pseudo-element, which generates the tooltip only when the user hovers over the icon, making the design interactive and user-friendly.

The tooltip is styled with a light gray background (background-color: #555) and white text, providing a subtle yet noticeable guide for the user without cluttering the interface.

3.5.3 Container

The container of the web page in Figure 24 is designed to hold the primary interactive elements, such as the ArcGIS map iframe and the "New Observation" button. This section plays a pivotal role in presenting data to users in a structured and responsive manner, ensuring that the wildlife observation data is easily accessible and visually appealing. The layout of the container is handled with CSS Flexbox, ensuring the section adapts smoothly across different device screen sizes.

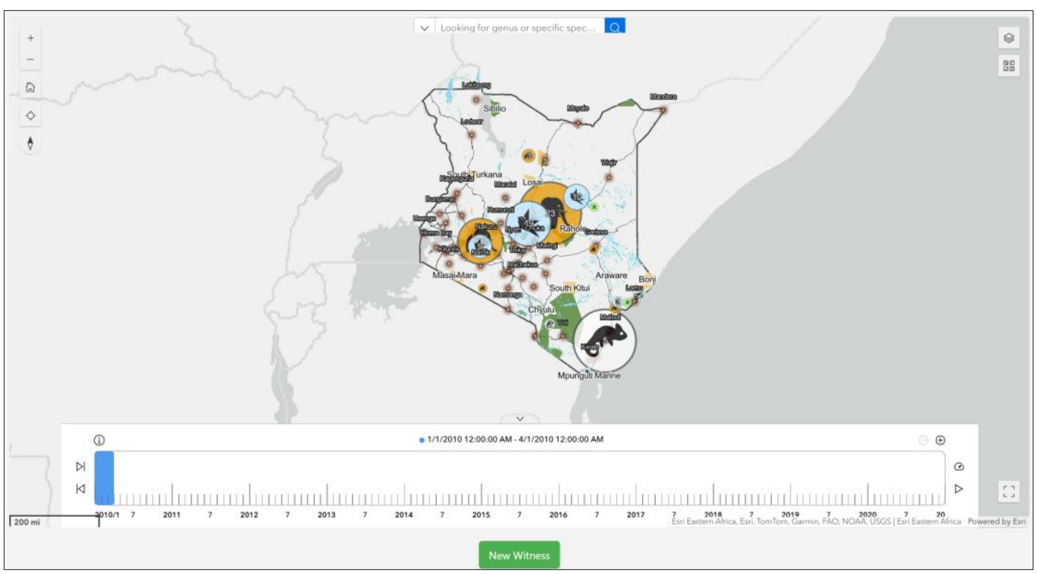


Figure 24. Maps and Other Elements in the Container

The container section is implemented using the HTML <div> element with the class container. It is a flexible container that adapts the layout depending on the content inside it, making it well-suited for housing the interactive elements of the site (Figure 25).

```html
<div class="container">
    <div class="tabs-container">
        <h2>Observation Record 2010-2020</h2>
        <div class="tabs">
            <a href="https://urldefense.com/v3/__https://www.brilliant-africa.com/kenya/wildlife__;!!LIr3w8kk_Xxm!r87YhcRHKC9xJi-PFAKkMRs-n4TzdxF7uWdPJXgQ7QrnzVLeV-zSa4kgAvCtWn6QXtccp8xr7e_On3Oc$"
            target="_blank">Wildlife in Kenya</a>
            <a href="https://urldefense.com/v3/__https://api.worldanimalprotection.org/country/kenya__;!!LIr3w8kk_Xxm!r87YhcRHKC9xJi-PFAKkMRs-n4TzdxF7uWdPJXgQ7QrnzVLeV-zSa4kgAvCtWn6QXtccp8xr7fODx9Ei$"
            target="_blank">Animal Protection</a>
            <a href="https://urldefense.com/v3/__https://www.kws.go.ke__;!!LIr3w8kk_Xxm!r87YhcRHKC9xJi-PFAKkMRs-n4TzdxF7uWdPJXgQ7QrnzVLeV-zSa4kgAvCtWn6QXtccp8xr7dnHjTJX$"
            target="_blank">Wildlife Service</a>
            <a href="https://urldefense.com/v3/__https://www.sheldrickwildlifetrust.org/projects/anti-poaching__;!!LIr3w8kk_Xxm!r87YhcRHKC9xJi-PFAKkMRs-n4TzdxF7uWdPJXgQ7QrnzVLeV-zSa4kgAvCtWn6QXtccp8xr7ZV6j2df$"
            target="_blank">Anti-Poaching</a>
        </div>
    </div>

    <div class="iframe-container" aria-label="Observation Record 2010-2020">
        <iframe id="experienceIframe" src="https://experience.arcgis.com/experience/43ca3f5bd95145f5b53dbce7c9d0a64a" title="Observation Record"></iframe>
    </div>

    <a href="https://survey123.arcgis.com/share/e613e2569c6c4744bf47f97f2cc2d932?portalUrl=https:**AUSCSSI.maps.arcgis.com__;Ly8!!LIr3w8kk_Xxm!r87YhcRHKC9xJi-PFAKkMRs-n4TzdxF7uWdPJXgQ7QrnzVLeV-zSa4kgAvCtWn6QXtccp8xr7R1FXYhK$"
    target="_blank" class="survey-link">New Observation</a>
</div>
```

Figure 25. HTML for the Container and “New Observation” Button

The Flexbox layout model is used to ensure the internal content is arranged in a manner that adapts to varying screen widths. The flex-direction: column property ensures that all the elements (the additional resources links, iframe, and "New Observation" button) are stacked vertically in a column. The use of Flexbox allows the layout to adjust dynamically based on the available screen space, providing a seamless user experience regardless of device (Figure 26).

```css
/* Container */
.container {
    flex: 1;
    display: flex;
    flex-direction: column;
    justify-content: space-between;
    overflow-y: auto;
    padding: 10px;
}

.tabs-container {
    display: flex;
    justify-content: space-between;
    align-items: center;
    margin-bottom: 10px;
    flex-wrap: wrap;
}

.tabs-container h2 {
    margin: 0;
    font-size: 1rem;
    font-weight: normal;
}

.tabs {
    display: flex;
    gap: 10px;
    flex-wrap: wrap;
    justify-content: center;
}

.tabs a {
    color: white;
    text-decoration: none;
    padding: 5px 10px;
    background-color: #333;
    border-radius: 5px;
    transition: background-color 0.3s;
    font-size: 12px;
}

.tabs a:hover {
    background-color: #555;
}
```

Figure 26. CSS Expression for the Container Structure and Layout

The container is given padding (padding: 10px), which helps maintain spacing between the contents and the edges of the screen. This creates a clean and visually appealing layout, enhancing the readability and usability of the page elements.

The ArcGIS map iframe is embedded within a separate container to ensure that the map fits within the page while maintaining its aspect ratio. This section uses an advanced CSS trick involving padding to make the iframe responsive while preserving the integrity of the content displayed.

In Figure 27, the iframe container uses percentage-based padding (padding-top: 50%) to ensure that the iframe's height always remains 50% of its width, thereby maintaining a 2:1 aspect ratio. This technique is particularly effective for making the iframe responsive, allowing it to scale properly on both large desktop monitors and smaller mobile devices without distortion. Also, it is positioned absolutely within the container (position: absolute), meaning it fills the available space completely without interfering with other elements on the page. This allows the map to occupy the entire container while adjusting to different screen sizes without introducing scrollbars or cutting off any part of the content. Rounded corners (border-radius: 5px) are used to soften the appearance of the iframe container, making it visually consistent with the rest of the design elements on the page, such as the buttons and links. This helps create a cohesive and professional look.

```css
.iframe-container {
    position: relative;
    width: 100%;
    padding-top: 50%;
}

.iframe-container iframe {
    position: absolute;
    top: 0;
    left: 0;
    width: 100%;
    height: 100%;
    border: none;
    border-radius: 5px;
}
```

Figure 27. CSS Expression for iframe

The "New Observation" button is placed below the iframe and provides users with a way to submit new wildlife observation records. This button links to an external survey tool, allowing users to contribute data in a structured format.

The button is centrally aligned below the iframe, ensuring that it is both easily accessible and visually distinct from the map. It is styled with a green background (background-color: #4CAF50), which is consistent with the site's overall environmental and wildlife theme. The button changes color on hover (background-color: #45a049) and slightly increases in size (transform: scale(1.05)), providing visual feedback and encouraging interaction (Figure 28).

```
/*New Observation */
.survey-link {
    display: block;
    max-width: 200px;
    padding: 10px 15px;
    background-color: #4CAF50;
    color: white;
    text-decoration: none;
    text-align: center;
    border-radius: 5px;
    transition: background-color 0.3s, transform 0.2s;
    margin: 20px auto;
    box-shadow: 0px 4px 6px rgba(0, 0, 0, 0.1);
}

.survey-link:hover {
    background-color: #45a049;
    transform: scale(1.05);
}
```

Figure 28. CSS Expression for the New Observation Link

3.5.4 Footer

Positioned at the bottom of the page, the footer is designed to remain fixed, ensuring that the information it contains is always visible, regardless of how the user navigates the page (Figure 29).

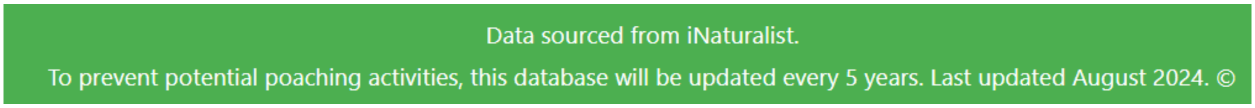


Figure 29. Footer Appearance

The footer section of the web application serves both a functional and informational role, providing users with a concise disclaimer about the data used, while also contributing to the overall aesthetic consistency of the page (Figure 30).

```html
<div class="footer">
    <p>Data sourced from iNaturalist. </p>
    <p>To prevent potential poaching activities, this database will be updated every 5 years.
</div>
```

Figure 30. HTML Expression for the footer

In Figure 31, the footer is styled with a green background color (#4CAF50), consistent with the rest of the page's environmental and wildlife-themed design. This creates visual continuity across the entire application and reinforces the theme of wildlife conservation. The text within the footer is set in white (color: white), ensuring high contrast and readability. The information conveyed includes a reference to the data source, iNaturalist, and a notice about the frequency of database updates, which is designed to minimize poaching risks by delaying the public release of new data.

```css
/* Footer */
.footer {
    background-color: #4CAF50;
    color: white;
    text-align: center;
    padding: 10px;
    box-shadow: 0 -1px 5px rgba(0, 0, 0, 0.1);
    width: 100%;
    position: relative;
    bottom: 0;
    left: 0;
    font-size: 0.8em;
}

.footer p {
    margin: 5px 0;
}
```

Figure 31. CSS Expression for the Footer

3.5.5 Instruction Video Pop-up

The "How It Works" video pop-up in Figure 32 is designed to give users a visual tutorial on how to navigate and interact with the web application. By embedding an instructional video, Figure 33, directly into the web interface, users can learn the app's functionalities, such as submitting new observations, exploring the wildlife map, and understanding the significance of the data displayed. The pop-up is designed to be unobtrusive and can be triggered on demand when users click the question mark icon in the header.

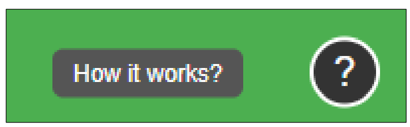


Figure 32. Hovering Text for Help Icon

The video is displayed in a modal pop-up that overlays the page, ensuring that users can access the information without being redirected to an external site. This design choice keeps users engaged and focused on the application while enhancing their experience.

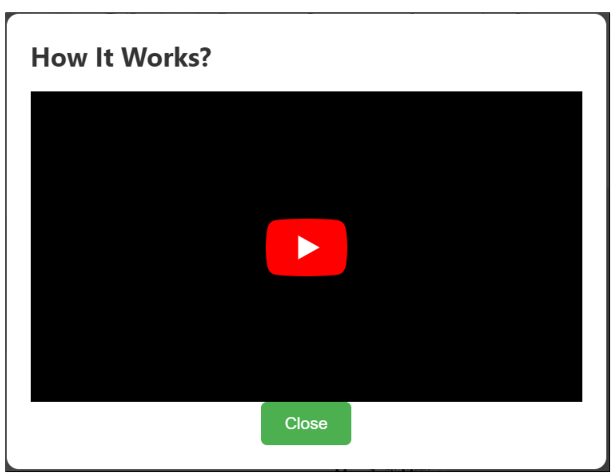


Figure 33. Instruction Video Appearance

This Pop-up is designed to provide users with an intuitive guide on how to navigate the web application. The HTML structure in Figure 34 utilizes a modal component that overlays the main content and temporarily captures the user's focus. The modal is triggered when the user clicks on the question mark icon, located on the right side of the header, providing an immediate way for users to access instructions.

```html
<div id="howItWorksModal" class="modal">
    <div class="modal-content">
        <h2>How It Works?</h2>
        <div style="position:relative;width:100%;height:0;padding-bottom:56.25%;">
            <iframe src="https://www.youtube.com/embed/YOUR_VIDEO_ID" style="position:absolute;width:100%;height:100%;left:0;top:0;border:0;" allowfullscreen></iframe>
        </div>
        <button class="close-btn" onclick="closeModal('howItWorksModal')">Close</button>
    </div>
</div>
```

Figure 34. HTML Expression for the Instruction Video

The modal itself is defined using a <div> element with a unique ID (howItWorksModal), allowing it to be targeted by JavaScript functions for both opening and closing. Inside the modal, there is a <h2> heading that briefly describes the purpose of the video, followed by the main content, which is an embedded YouTube instructional video. The video is displayed through an <iframe> element, which is styled to maintain a 16:9 aspect ratio across various screen sizes. This is achieved using CSS properties such as position: relative and padding-bottom: 56.25%, ensuring that the video remains responsive and adjusts to different devices.

Additionally, the modal includes a "Close" button at the bottom, which allows users to exit the pop-up once they have finished viewing the video. This button triggers a JavaScript function that changes the display property of the modal, making it invisible and returning the user to the main application.

The CSS used for the "How It Works" video pop-up shares similarities with the design of the Welcome Message pop-up (Figure 35). The .modal class is responsible for the full-screen overlay effect, and the Flexbox (justify-content: center; align-items: center;) to center the content both horizontally and vertically, ensuring a seamless user experience across different screen sizes.

```css
@media (max-width: 768px) {
    .title-container {
        font-size: 1.2rem;
        padding: 0.5rem 0;
    }
    .question-mark {
        position: static;
        margin-top: 10px;
        margin-left: auto;
    }
    .tabs-container h2 {
        font-size: 0.9rem;
        margin-bottom: 5px;
        width: 100%;
        text-align: center;
    }
    .iframe-container {
        margin-top: 10px;
    }
    .survey-link {
        margin-top: 10px;
    }
    .footer {
        padding: 5px;
        font-size: 0.7em;
    }
    .modal-content {
        padding: 15px;
    }
}

@media (max-width: 480px) {
    header {
        flex-direction: column;
        padding: 0.5rem;
    }
    .title-container {
        font-size: 1rem;
    }
    .navbar a {
        font-size: 12px;
        padding: 5px 10px;
    }
    .question-mark {
        width: 30px;
        height: 30px;
        font-size: 16px;
    }
    .tabs-container h2 {
        font-size: 0.8rem;
    }
    .tabs a {
        font-size: 10px;
        padding: 3px 8px;
    }
    .footer {
        padding: 5px;
        font-size: 0.6em;
    }
    .modal-content {
        padding: 10px;
        font-size: 0.9rem;
    }
    .close-btn {
        padding: 8px 15px;
        font-size: 12px;
    }
```

Figure 35. CSS Expression for the Instruction Video

While the structure remains consistent with the Welcome Message, the How It Works pop-up has additional CSS for video embedding. The embedded video is styled within an iframe using a 16:9 aspect ratio trick (padding-bottom: 56.25%), ensuring that the video is responsive and scales appropriately across devices. This aspect is specific to the video pop-up, as it requires careful handling to ensure the iframe maintains its correct dimensions without distorting the layout.

This pop-up also includes a dedicated close button (.close-btn), which shares design features with the button used in the Welcome Message. The button is styled consistently, maintaining the app's color scheme, and providing a hover effect (background-color: #45a049) for a cohesive user experience.

The web framework of the Historical Kenya Wildlife Observation Map (Figure 36) was designed to create an engaging and user-friendly platform that effectively integrates wildlife data with public interaction. By leveraging responsive design principles and intuitive layouts, the framework ensures accessibility across various devices and user demographics. Integrating visual and interactive elements, such as the ArcGIS map, submission forms, and instructional pop-ups, demonstrates a thoughtful approach to combining technological functionality with aesthetic appeal. This framework supports the project's broader goal of promoting public engagement and enhancing awareness of wildlife conservation.

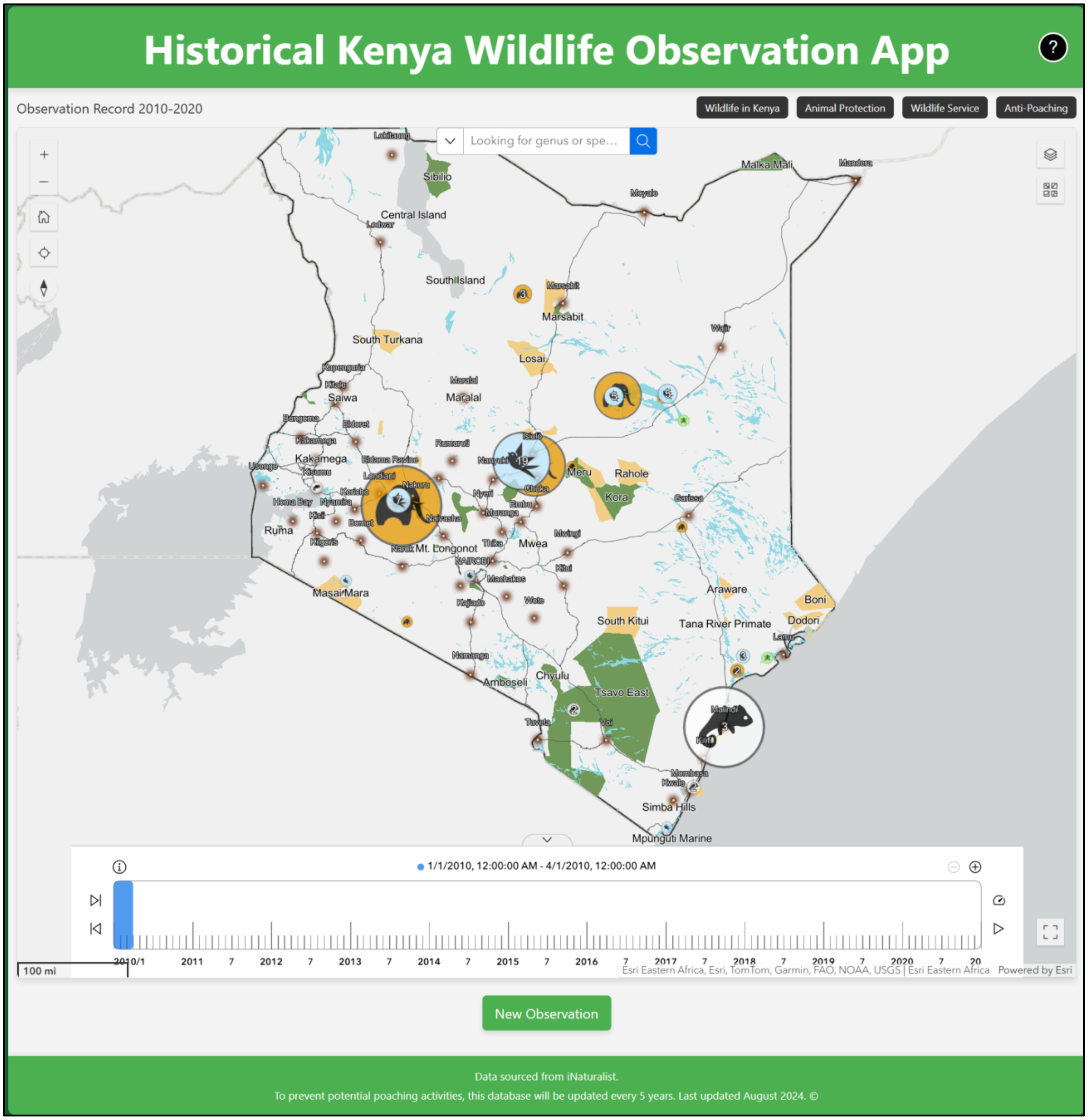


Figure 36. Historical Kenya Wildlife Observation App

Chapter 4. Results

This chapter discusses the results of the development and functionality of the Historical Kenya Wildlife Observation application. Section 4.1 focuses on the interactive map, the most crucial content for visualizing wildlife observations and exploring spatial data. Section 4.2 introduces the web design components, including user interface elements and the application's responsiveness across various devices. Section 4.3 covers the data collection survey integration through Esri Survey123, explaining how new wildlife observations are reported and managed. Each section highlights key features, design decisions, and user engagement strategies implemented in the application.

4.1 Interactive Map

The interactive map is the core feature of the Historical Kenya Wildlife Observation application, providing a detailed, user-friendly platform for visualizing wildlife observations across Kenya. The map is organized into multiple layers, each representing a taxonomic group.

On the bottom of the map is a time filter (Figure 37), allowing users to focus on specific periods within the 2010-2020 range. This temporal filter helps users to analyze changes in wildlife distribution over time, although only historical data is shown to protect sensitive information and prevent poaching.

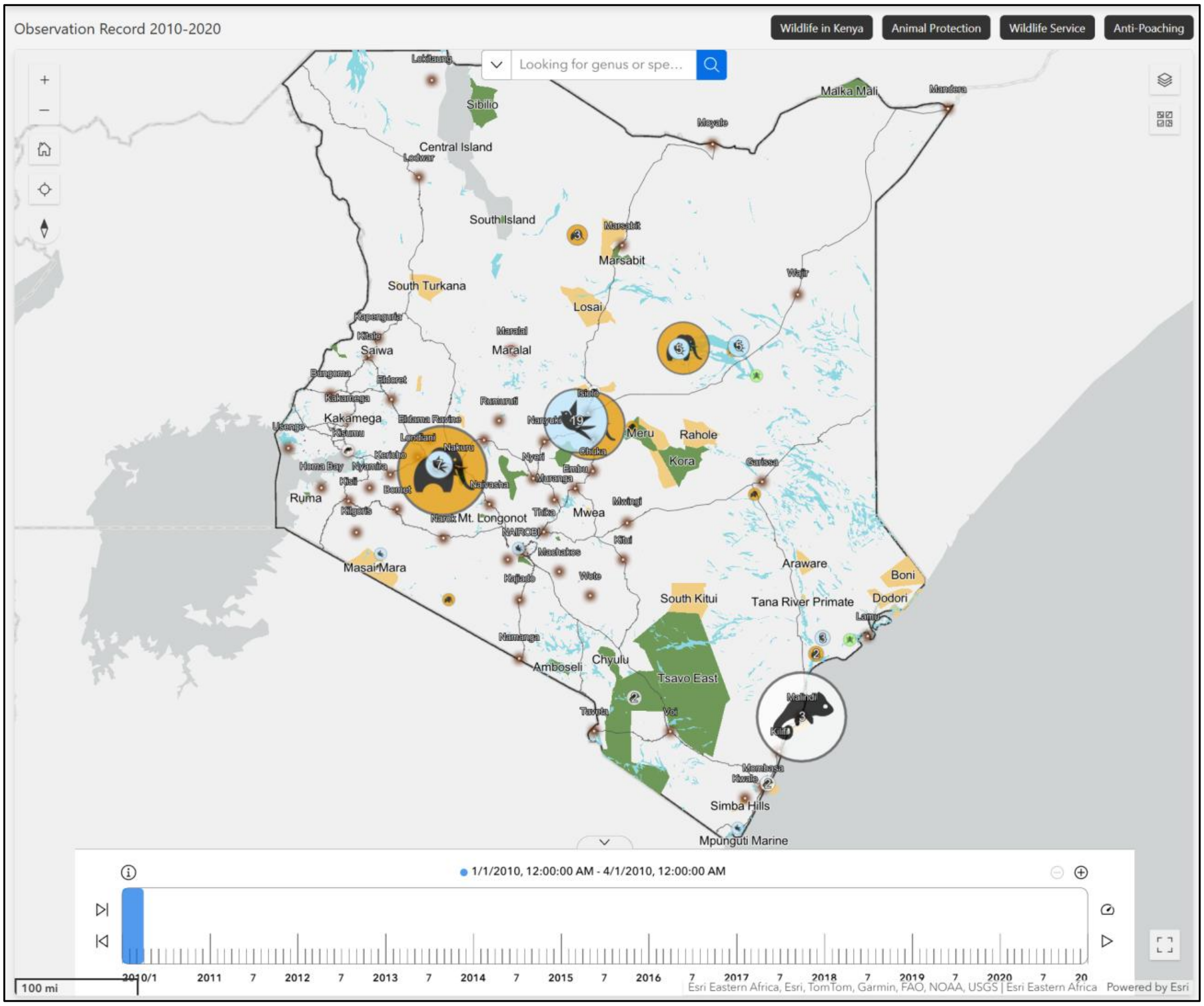


Figure 37. Web Map Appearance

In this map, each species group is represented by distinct icons that reflect the group's characteristics, with varying colors to ensure ease of interpretation, as shown in Figure 38. The map also incorporates clustering techniques to manage the display of dense data points in regions with numerous wildlife observations. As users zoom in, clusters break apart into individual points, allowing for detailed exploration without cluttering the display at broader scales.

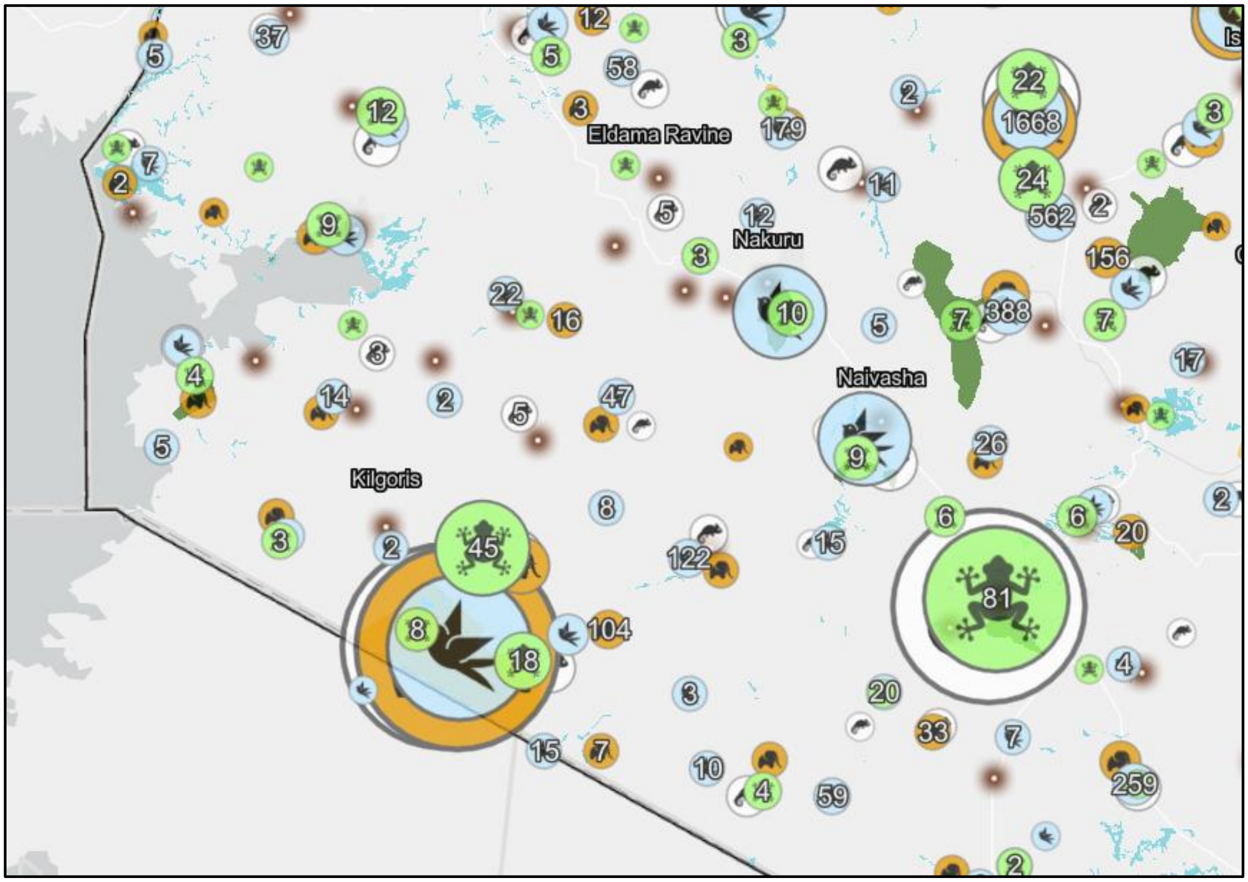


Figure 38. A Closer look for Symbology of Data Points

Several map elements enhanced the interactive experiences. On the top right of the map, a layer button is added so the users can turn on or off the layers they target for, which help them to concentrate on the specific data (Figure 39). Also, a dynamic legend is included to help users understand the symbology used for the different taxonomic layers. The legend updates based on the layers currently active, ensuring that users can easily interpret the data they are viewing.

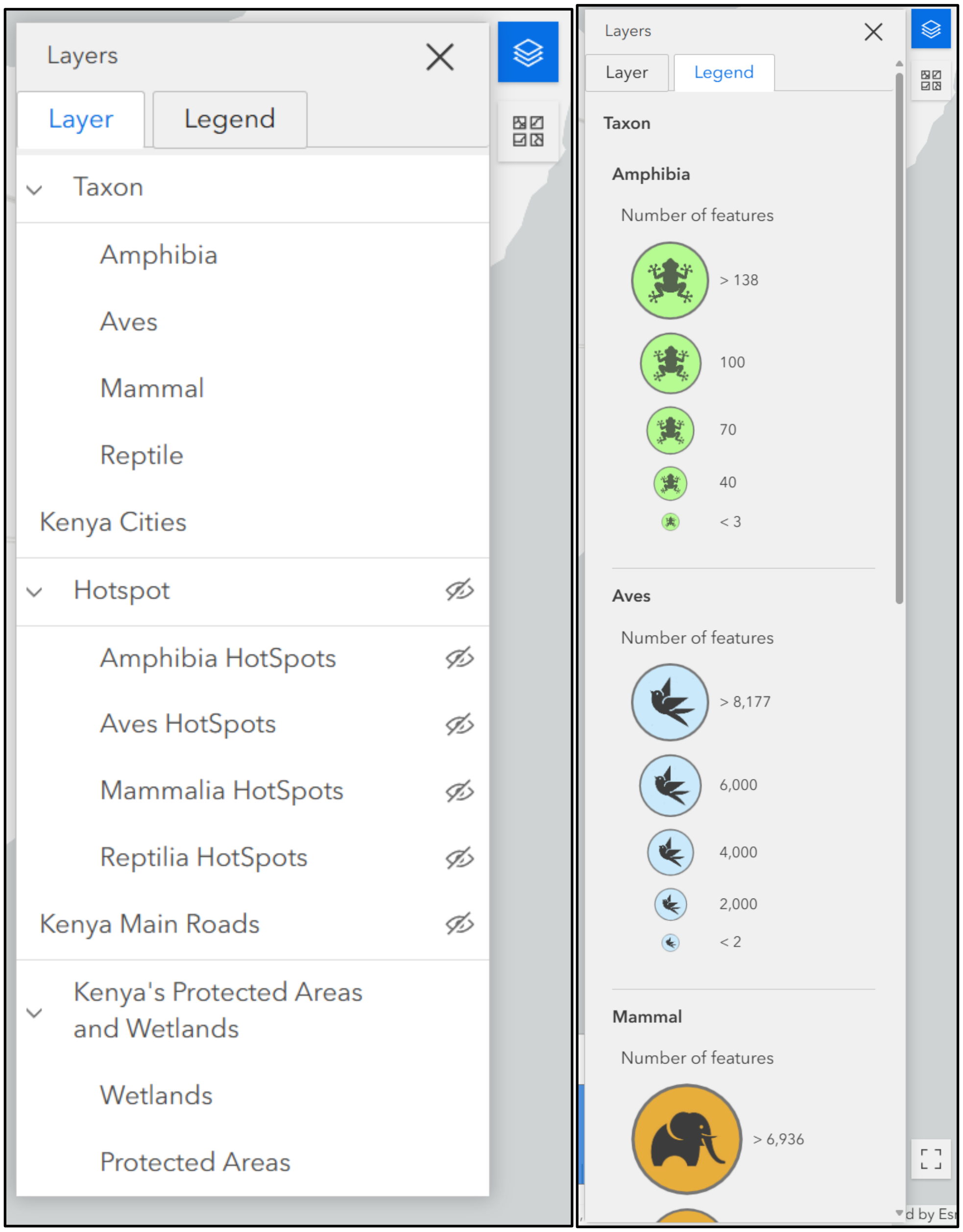


Figure 39. Layers Visualization

The map's default background uses a simple topographic base map, which provides essential geographical context without overwhelming the wildlife data. However, Users can change the base map based on preferences through the base map button at the top right (Figure 40).

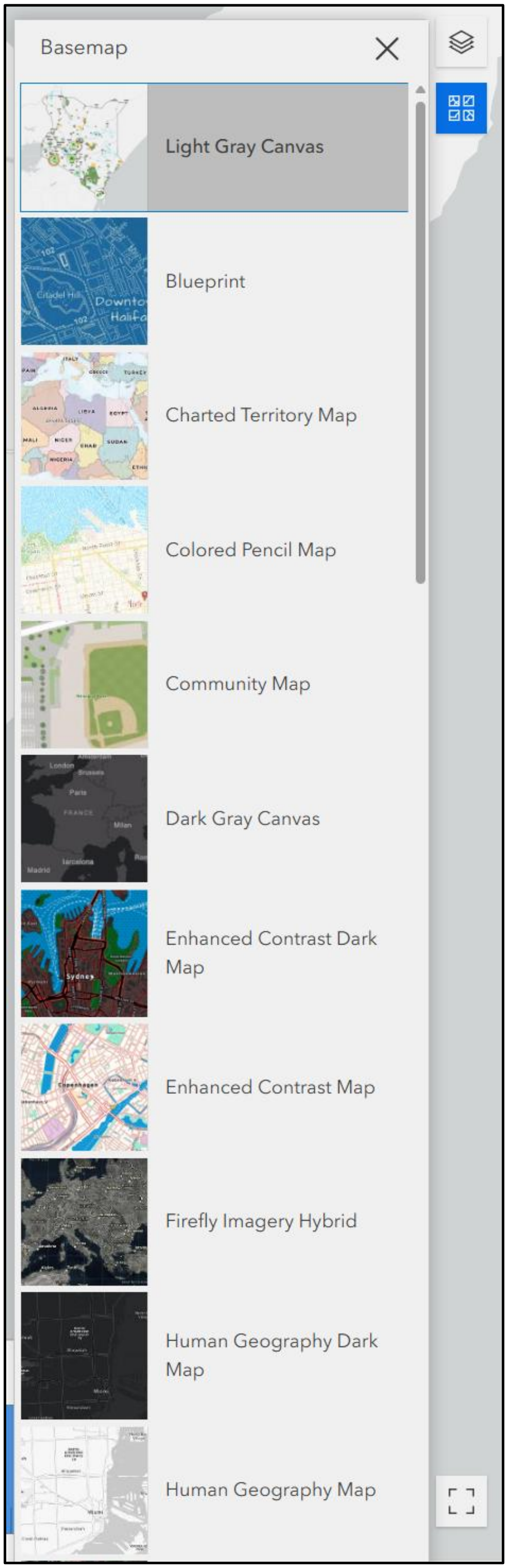


Figure 40. Basemap Options

Clicking on a data point reveals a pop-up with detailed information about the wildlife observation, including species name, observed time, and user uploaded images as shown in Figure 41. This feature encourages users to dive deeper into individual records.

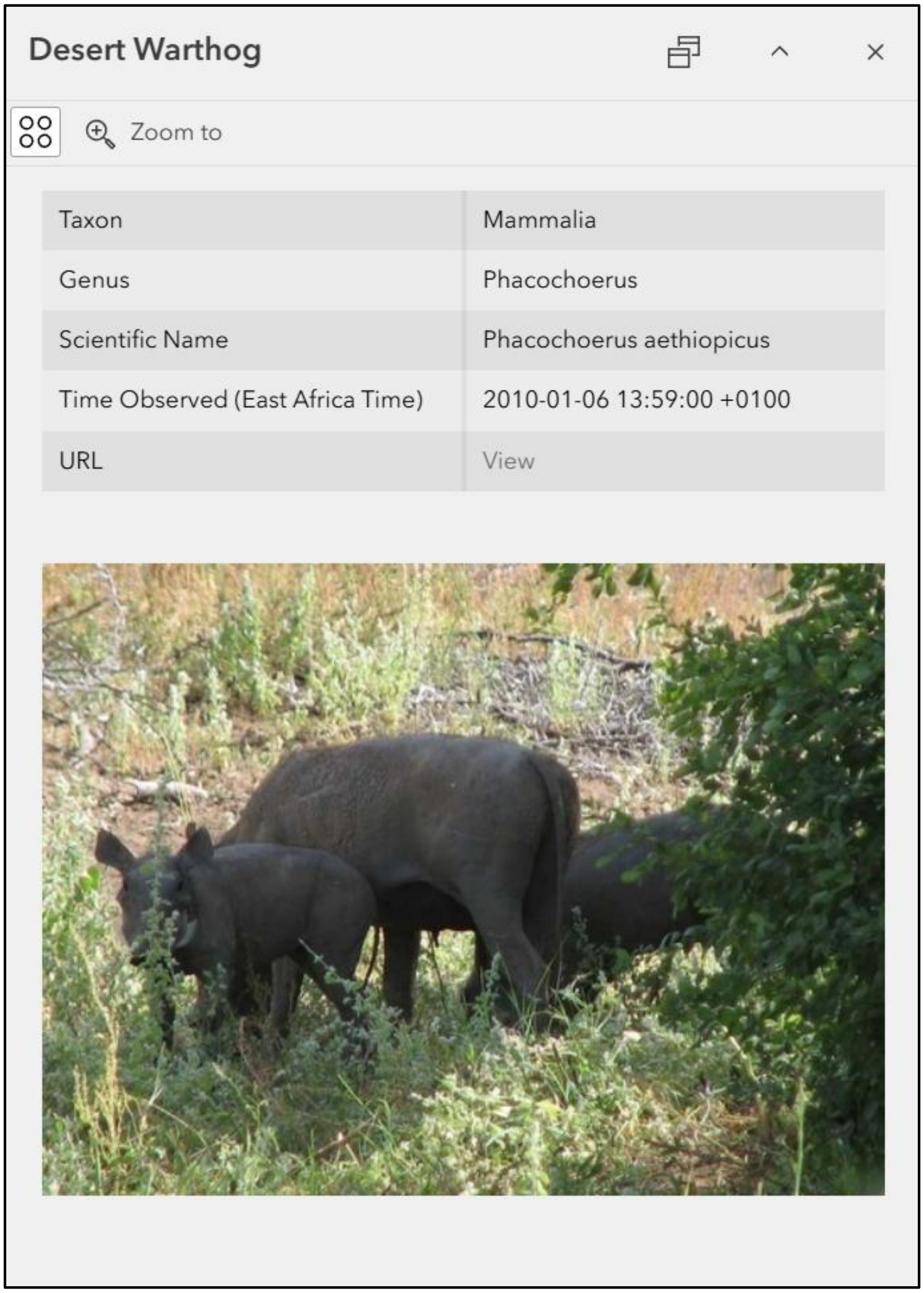


Figure 41. Pop-up Example

The hotspot analysis conducted in this study revealed several areas of significant wildlife activity, providing critical insights into biodiversity patterns within the region. Using the Getis-Ord Gi* statistic, high-density clusters of wildlife observations were identified, indicating ecological hotspots essential for species conservation. Taking Amphibia as an example in Figure 42. These clusters predominantly occurred in protected areas and along known migration corridors, highlighting their importance for maintaining biodiversity. Conversely, low-density clusters corresponded to regions impacted by human activities, such as urban development and agriculture, emphasizing the need for targeted conservation interventions.

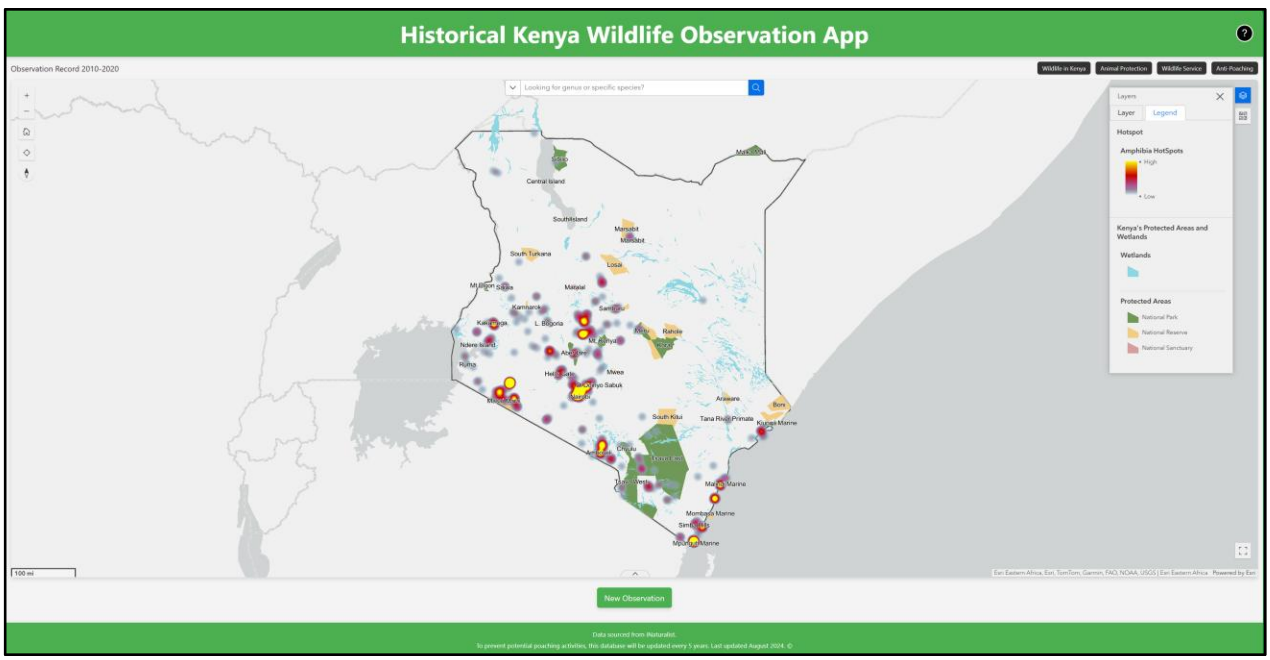


Figure 42. Hotspot Analysis for Amphibia

4.2 Web Appearance

The Historical Kenya Wildlife Observation application's web design is crafted to ensure both usability and aesthetic appeal, striking a balance between functionality and visual simplicity. As Figure 43, the design approach emphasizes an intuitive layout that caters to a broad audience that may include wildlife enthusiasts, researchers, and conservationists.

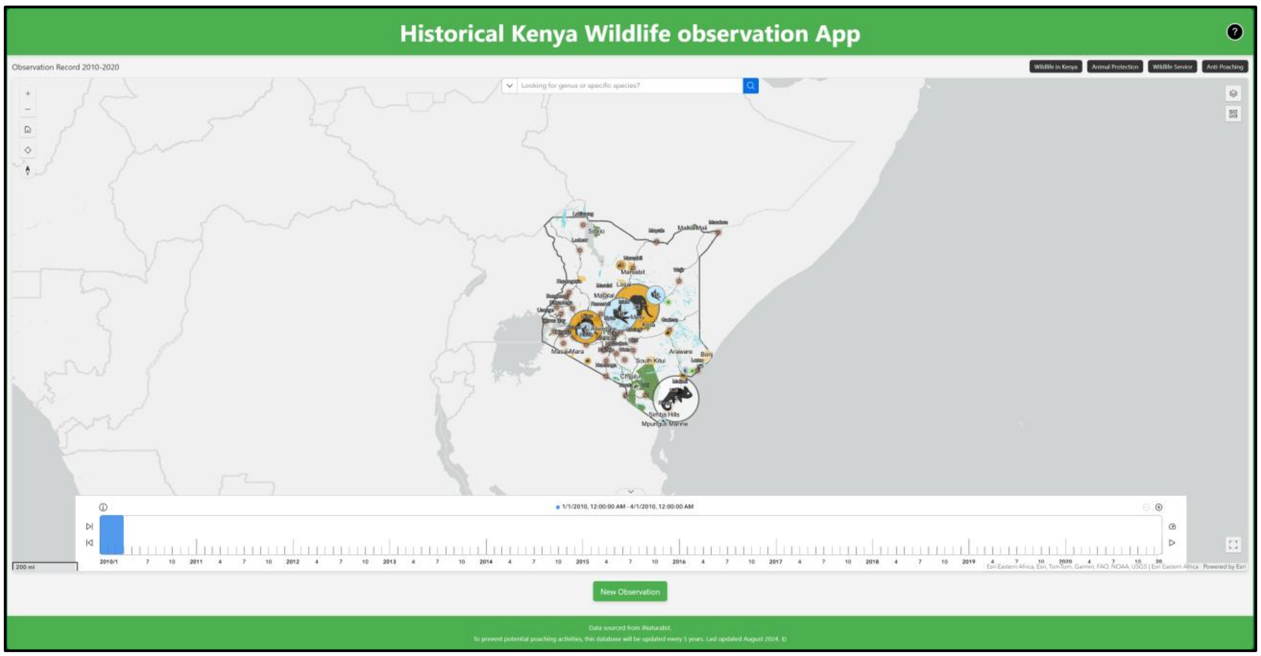


Figure 43. Web Appearance

The web's layout consists of three sections: the header, map, and footer. The header contains the title, additional resources links, and a question mark icon that opens a help pop-up when clicked. The title is centrally aligned for clarity, while the additional resources links provide quick access to external wildlife-related websites such as animal protection services and anti-poaching initiatives.

The map section occupies the bulk of the page to maximize the focus on the wildlife data. This prominent, central feature allows users to interact with the data immediately. Beneath the map, a "New Observation" button provides access to the Esri Survey123 form for submitting new wildlife observations.

The footer contains a short disclaimer regarding the source of the data and provides copyright information. It remains fixed at the bottom of the screen to ensure accessibility on all pages.

The application employs CSS Flexbox and media queries to ensure the web layout adjusts to different screen sizes. The map and additional resources components are displayed horizontally for larger screens, while on smaller screens (such as mobile devices, Figure 44), elements stack vertically to improve readability and usability. The additional resources links are moved into a collapsible menu on mobile devices to maximize space for the interactive map. The map dynamically resizes to fit the available screen, ensuring a consistent experience across all devices.

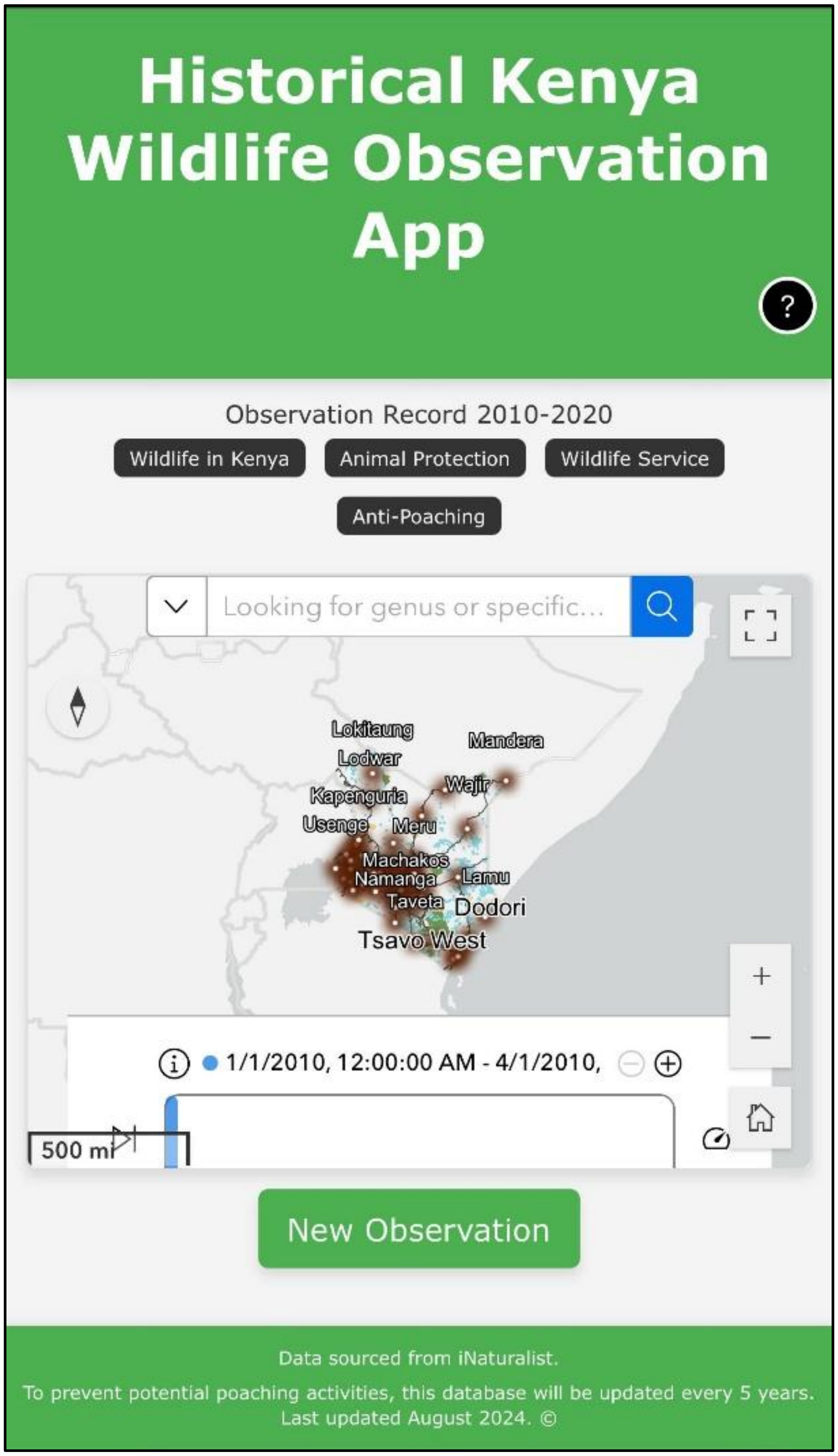


Figure 44. Wildlife Observation App Mobile View

Pop-up windows are used for the welcome message and the "How It Works" instructional video (Figure 45 and 46) on both mobile app and larger screens. These pop-ups are designed to be non-intrusive, using smooth transitions and consistent color schemes to enhance the user experience without interrupting the workflow.

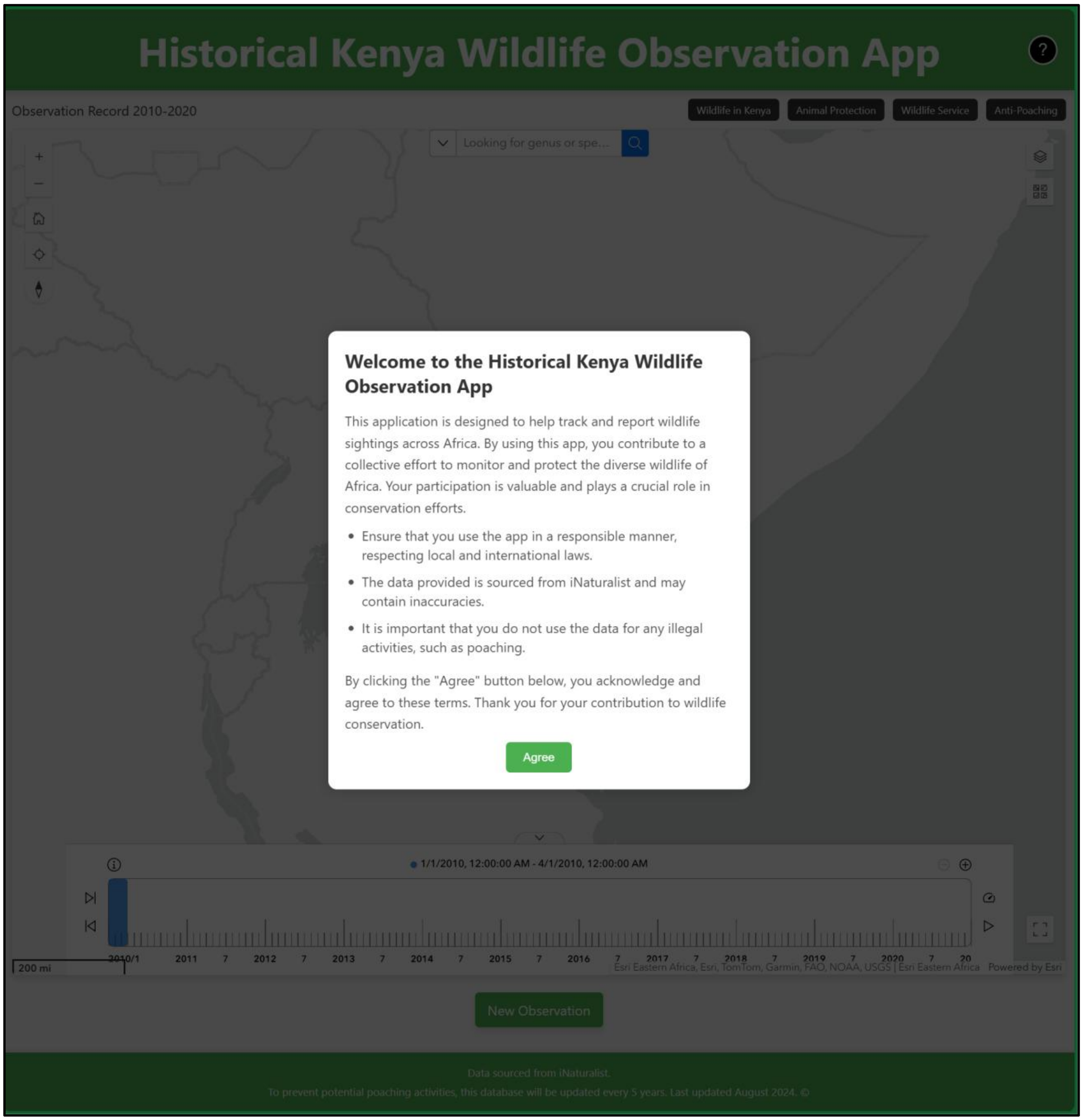


Figure 45. Welcome Message

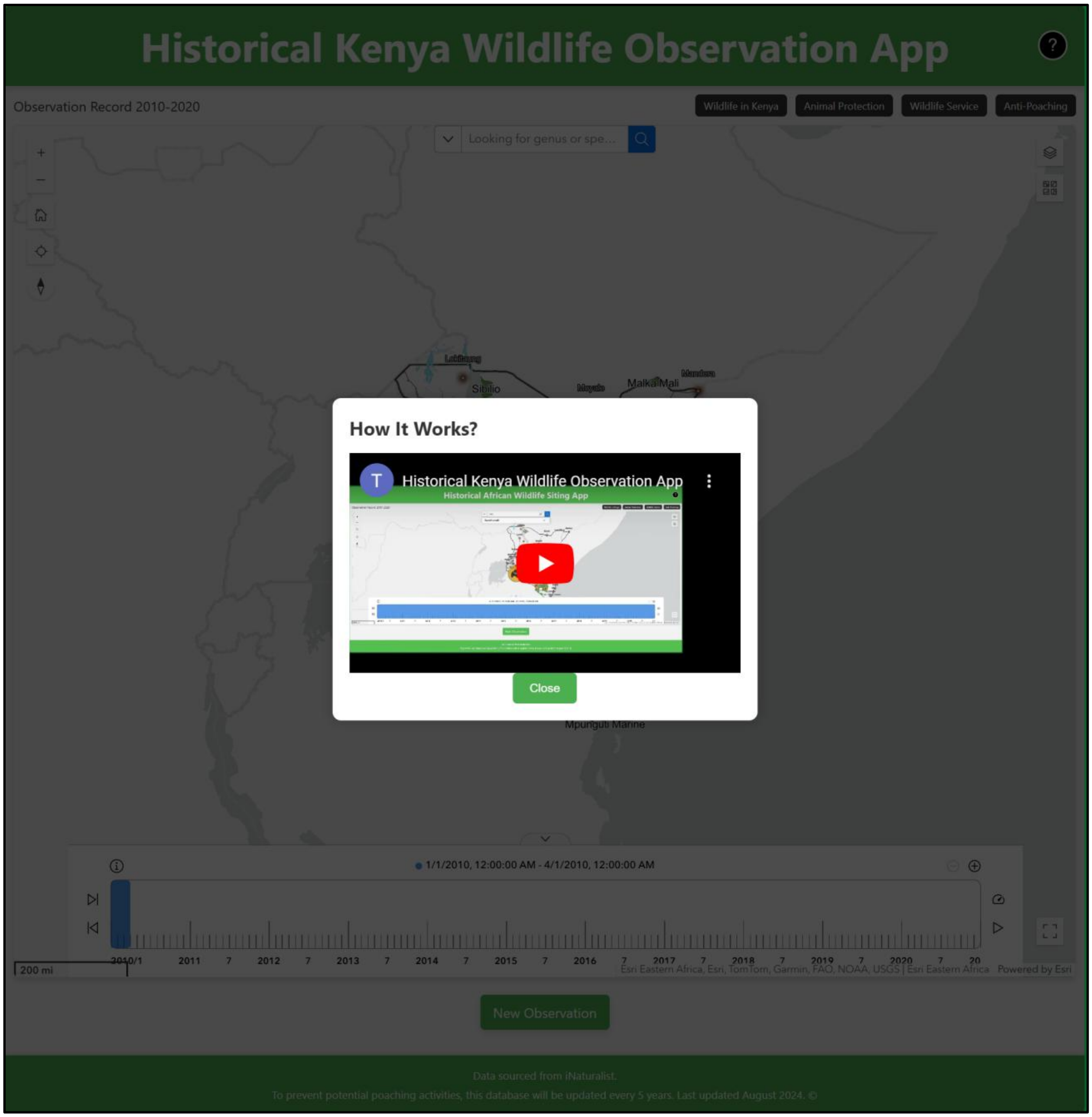


Figure 46. Instruction Video

4.3 Data Collection Survey

The data collection survey within the Historical Kenya Wildlife Observation application plays a pivotal role in gathering new wildlife observations from users. Built using Esri Survey123, the survey allows users to report their observations in real-time when connected to the internet, contributing to the growing repository of data used for wildlife conservation efforts.

The user-friendly design ensures that individuals with varying knowledge can easily submit their wildlife observations. This design follows a straightforward structure. The guides in each question aid the users in navigating. Key fields in the survey include the species observed, the date and time of the observation, the location, and the ability to upload photographs (Figure 47).

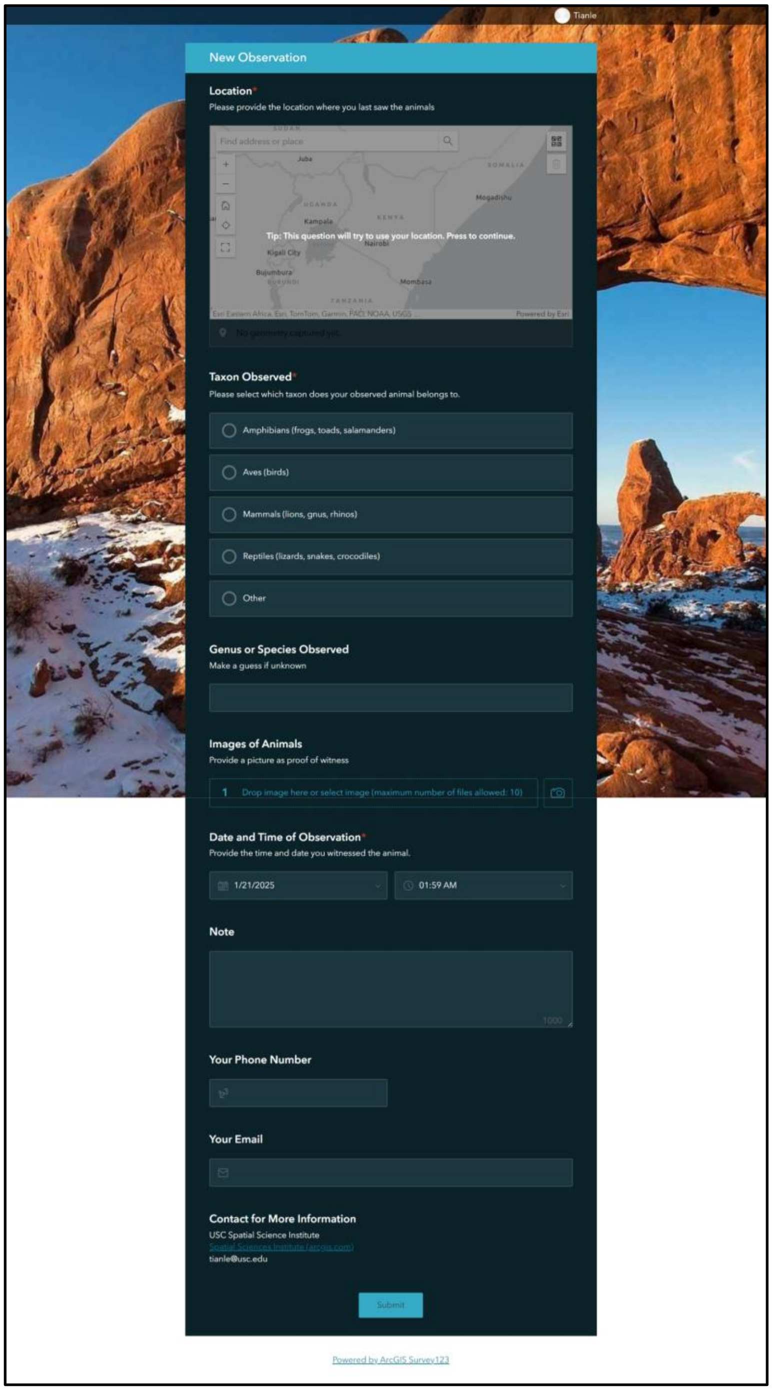


Figure 47. New Observation Form

The survey's visual design is integrated seamlessly into the overall application's aesthetic, using the same green and earth-tone color scheme as the rest of the web app. This consistency fosters a unified user experience and reinforces the app's conservation-focused theme.

Once the form is submitted, a thank-you message is displayed, and the data is automatically uploaded to an ArcGIS Online layer. This layer is set to be private due to the protection of wildlife, and the data will be updated for the application every five years (Figure 48).

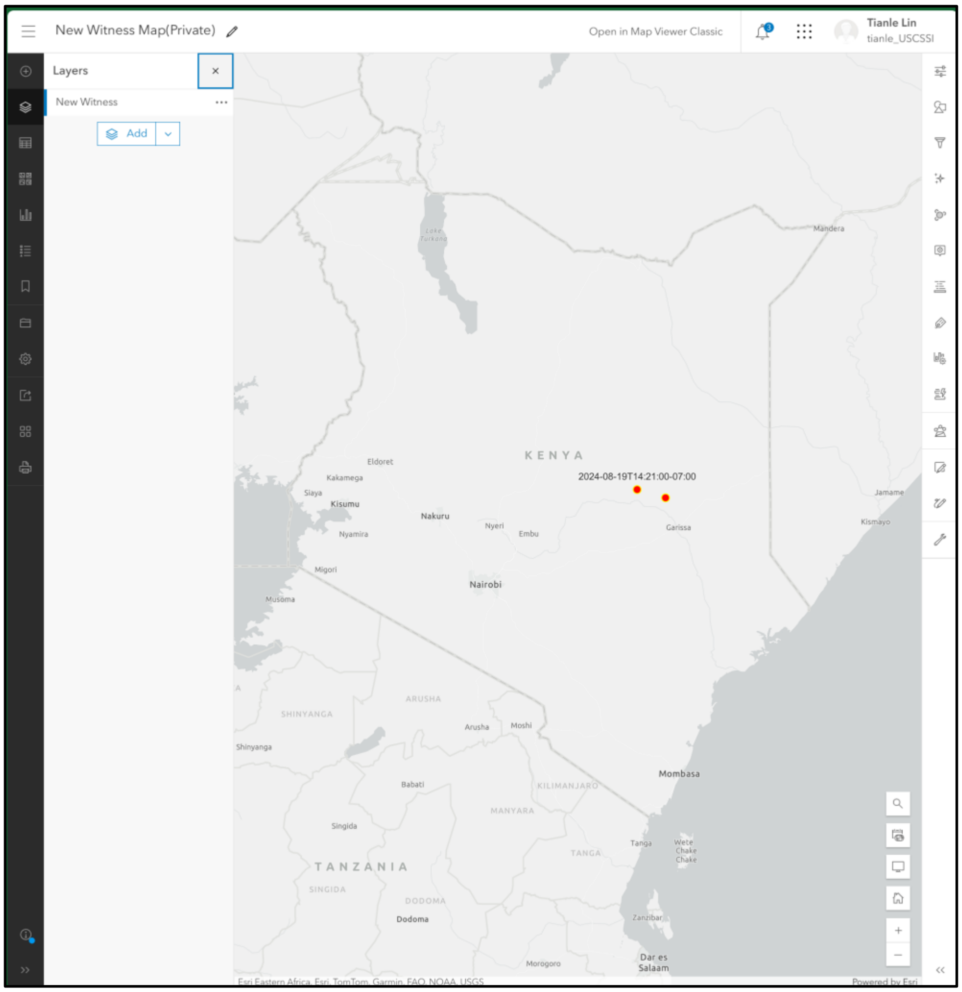


Figure 48. Layer Contains New Observed Points (Not Open to Public)

The results presented in this chapter highlight the effectiveness of the Historical Kenya Wildlife Observation Web Application in visualizing long-term wildlife data and identifying key spatial patterns. Integrating VGI from iNaturalist with GIS-based spatial analysis tools provides valuable insights into species distributions and ecological trends. Through interactive mapping and analytical functionalities, the platform enhances accessibility to wildlife data while supporting conservation decision-making.

However, several challenges and limitations emerged during the implementation process, including data accuracy concerns, visualization constraints, and ethical considerations regarding the public sharing of wildlife locations. These factors emphasize the need for continuous refinement of data integration strategies, symbology improvements, and ethical safeguards to protect sensitive species data from potential misuse.

Despite these limitations, this study demonstrates the potential of web-based GIS applications in biodiversity monitoring. The findings from this chapter provide the foundation for further discussion in Chapter 5, where the implications of these results will be examined in greater depth, along with recommendations for future improvements and potential expansion areas.

Chapter 5. Conclusions

This chapter delves into the distinctive outcomes of the Historical Kenya Wildlife Observation project, highlighting its success in creating an innovative platform that leverages community-contributed data to support wildlife conservation in Kenya. Section 5.1 revisits the project's unique objectives, such as integrating historical wildlife data with modern GIS technologies to produce an interactive and educational tool accessible to conservationists and the public. Section 5.2 focuses on the challenges encountered, including addressing data inaccuracies from VGI, overcoming ArcGIS platform limitations, and designing a responsive interface that balances functionality with user-friendliness. Finally, Section 5.3 outlines targeted areas for future improvement, such as incorporating real-time data streams, enhancing analytical capabilities, and fostering collaborations with conservation organizations to broaden the tool's impact. These discussions underscore the project's innovative approach to bridging technology, community involvement, and conservation science.

5.1 App Summary

The Historical Kenya Wildlife Observation project was developed to provide a user-friendly, interactive platform for historical wildlife observation and community-driven data collection. The main objective was to create a web-based application using ArcGIS tools that would allow users to access historical wildlife observations in Kenya, report new observations, and contribute to conservation efforts.

The project focused on integrating VGI data from iNaturalist, specifically targeting four taxonomic groups: Amphibians, Mammals, Aves, and Reptiles. Through a combination of ArcGIS Pro, ArcGIS Online, and ArcGIS Experience Builder, the application provided an intuitive interface for users to explore historical data from 2010 to 2020. Survey123 provided functions for new observation reporting. Collaborating with a responsive HTML web frame design ensured the platform was accessible across various devices.

The project successfully combined spatial data management, interactive mapping, and user engagement to promote public awareness of wildlife conservation. This web application identified all the major national parks and reserves within the study area, which helps users understand the potential causes of wildlife distribution. Temporal analysis features allow users to monitor seasonal and long-term changes in species distribution. Users can explore more information regarding Kenya's wildlife and conservation through the website linked in the web application. The 5-years data refresh rate helps to avoid illegal activities such as poaching.

However, the Historical Kenya Wildlife Observation Web Application is designed exclusively for this project. For access, please contact the project owner directly.

5.2 Historical Kenya Wildlife Observation Web Application VS. iNaturalist

5.2.1 Data Focus

iNaturalist is primarily designed to collect real-time observations from all over the world. In addition to wildlife, it also collects data on vegetation and fungus. The Historical Kenya Wildlife Observation Web Application is designed to focus on the four chosen taxa in Kenya. It will only present data from 2010-2020 and will only be updated every five years.

5.2.2 Spatial Analysis

In the Historical Kenya Wildlife Observation Web Application, critical wildlife habitats are highlighted with different colors to guide users with the study area. Spatial analysis tools, such as hotspot analysis and temporal clustering are employed to help users understand the wildlife distribution better. A time slide is also added to help users focus data on a specific time range. However, iNaturalist does not provide any spatial analysis tools, instead offering raw observation data that can be exported for external analysis.

5.2.3 Map Accessibility

In the Historical Kenya Wildlife Observation Web Application, accessibility features have been integrated to enhance user experience and ensure inclusivity. Different icons were applied to represent each taxon—Amphibians, Mammals, Aves, and Reptiles—making it easier for users to distinguish between species groups immediately. To further assist users in navigating the map, a legend with detailed information about the symbology and layers is prominently displayed. Additionally, an instruction video is provided, offering a step-by-step guide on how to browse and utilize the web application effectively.

In contrast, iNaturalist employs a simpler approach to map symbology, using uniform points to represent all observations. While this simplicity makes the map less cluttered, it can cause confusion when users attempt to locate or analyze specific taxon data. Moreover, iNaturalist only provides several guidance links that composed by text and pictures to help users, which can be difficult to new users.

5.3 Challenges and Limitations

The development of the Historical Kenya Wildlife Observation project encountered several challenges related to data integration, software constraints, and user accessibility. This section provides a detailed overview of these challenges and discusses the solutions implemented during the project.

5.3.1 Data Integration and Cleaning

Integrating VGI from iNaturalist introduced challenges such as inaccurate geolocations, incorrect species identifications, and missing metadata. Addressing these issues required extensive data-cleaning processes in ArcGIS Pro. Critical tasks included removing duplicate records and standardizing metadata fields, enabling local geodatabase integration. ArcGIS Pro tools were developed to identify and flag duplicate entries, reducing manual workload and improving dataset accuracy. Misplaced data points were corrected by cross-referencing with authoritative geographic layers, ensuring higher data integrity.

5.3.2 Software Limitations in ArcGIS Suite

During the project, customization constraints within ArcGIS Experience Builder (patch 10.9) presented challenges. The platform's built-in functionalities limited the ability to tailor the interface fully to the project's requirements. Custom CSS and JavaScript were employed to overcome these limitations, enhancing the design and expanding the platform's capabilities. Integration of Survey123 provided flexible data entry forms, allowing users to submit new observations easily.

Another significant challenge was optimizing performance, especially when handling large datasets on ArcGIS Online. The project initially faced performance bottlenecks, including slower loading times and occasional lags. These issues were mitigated by implementing data filters to limit the number of visible features at any given time and setting visibility ranges to control the display of layers based on zoom levels. These measures significantly enhanced the application's responsiveness and ensured a smoother user experience.

5.3.3 User Accessibility and Interface Design

Ensuring a responsive and intuitive user interface was a core objective of the project. To achieve this, a layout that adapted seamlessly across various devices, including desktops, tablets, and mobile phones, was designed. CSS Flexbox was utilized to ensure that elements resized and repositioned effectively, providing a consistent user experience regardless of screen size. This responsive design helped maintain the platform's accessibility, enabling users to interact with the application without disruption across different devices.

A key focus was also on making the platform simple and user-friendly. Dropdown menus, tooltips, and clear call-to-action buttons were incorporated to facilitate easy navigation. Additionally, a help icon linked to an instructional video provided users with guidance on navigating the platform and using its features. This feature can be beneficial for first-time users, enhancing their experience by offering step-by-step explanations.

These solutions collectively addressed the primary challenges encountered during the project, ensuring that the platform remained functional, accessible, and user-friendly. By overcoming these obstacles, the project created a robust tool for tracking and reporting wildlife observations, thus supporting broader conservation efforts.

5.3.4 Potential Competitors

During this research, Esri and iNaturalist released a beta version of a wildlife tracking map in June 2024. While this tool was not available during the early phases of the project, it highlights the rapid advancements in GIS and VGI technologies for conservation. However, the Historical Kenya Wildlife Observation web application does not aim for profitable goals and primarily serves as this project's product; this development affirms the necessity of this work and its focus on addressing region-specific needs, such as historical data integration and enhanced visualization. Future iterations of this project could explore synergies with these emerging tools, leveraging their capabilities to enhance biodiversity monitoring and public engagement further.

5.4 Future Work

The Historical Kenya Wildlife Observation project successfully established a platform for tracking and reporting wildlife observations across Kenya. However, there remains significant scope for future enhancements and expansions. This section outlines potential future work that could build upon the current framework to improve the platform's functionality, usability, and impact further.

5.4.1 Enhanced Data Integration

Future work could focus on expanding the types and sources of data integrated into the platform. Currently, the platform primarily relies on VGI data from iNaturalist, but incorporating real-time data streams from the iNaturalist API could significantly enhance functionality. This API allows access to live biodiversity records, enabling automatic updates and providing the most recent observations for more dynamic conservation planning (iNaturalist API 2025; iNaturalist GitHub 2025). Additionally, integrating data from other platforms, such as eBird (eBird) or automated wildlife tracking systems, would enrich the dataset. Advanced technologies like GPS collars or acoustic sensors could further improve wildlife monitoring capabilities. However, strict rules and methods are required to avoid poaching.

5.4.2 Advanced Data Analytics and Visualization

While the current platform offers basic map-based visualizations, future enhancements could include more sophisticated data analysis and visualization tools. For instance, heat maps, trend analyses, and species distribution models could provide deeper insights into wildlife behavior and movement patterns. Additionally, the platform could implement AI-driven predictive analytics to forecast potential changes in species distribution based on historical data and environmental factors. This would be especially useful for conservation planning and resource allocation.

5.4.3 Improved User Experience and Interface Design

Despite efforts to make the platform responsive and user-friendly, there are still areas where the user interface could be further refined. Future work could explore the development of more interactive map elements, such as how weather affect the distribution of wildlfie. Enhanced filtering options would allow users to customize their viewing experience, making focusing on specific species or regions of interest easier. Moreover, multilingual support could broaden the platform's accessibility, enabling users from different linguistic backgrounds to engage with the tool more effectively.

5.4.4 Enhanced Data Security and Privacy

Given the sensitivity of some wildlife data, especially concerning endangered species, future work should focus on enhancing data security and privacy. Implementing more robust encryption protocols and secure data access controls could prevent the unauthorized use of sensitive information. Additionally, further establishing a system for anonymizing location data could provide better privacy protections, ensuring that the platform remains compliant with ethical standards for wildlife conservation and data sharing.

5.4.5 Expanded Educational and Outreach Features

The platform's potential as an educational tool for raising awareness about wildlife conservation could be further developed. Future versions could incorporate more educational content, such as interactive tutorials, species fact sheets, and information on conservation practices. Collaborations with schools and conservation organizations could lead to the development of learning modules, quizzes, or even live-streamed events, enhancing public engagement and understanding of wildlife conservation issues.

5.4.6 Broader Geographic Expansion

Future iterations of the platform aim to improve its capabilities and expand its geographic scope beyond Kenya. By adapting to include diverse datasets and addressing region-specific challenges, the platform could evolve into a comprehensive wildlife monitoring tool for Africa or even globally. Collaborations with international conservation organizations could facilitate data-sharing agreements and create a broader network of contributors, making the platform a go-to resource for wildlife data worldwide.

Addressing these areas of future work can make the Historical Kenya Wildlife Observation project a more robust and versatile tool. Continuous development will enable it to play a more significant role in global wildlife conservation, supporting efforts to understand and protect biodiversity on a larger scale.

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